STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY, TRANSPORTATION
MATERIALS & RESEARCH
OFFICE OF TRANSPORTATION MATERIALS & RESEARCH

# TRAFFIC NOISE ATTENUATION AS A FUNCTION OF GROUND AND VEGETATION (INTERIM REPORT)


Study Supervised by .................. Mas M. Hatano, P.E. and Paul Benson, P.E.

Principle Investigator ............... Rudy Hendriks

Report Prepared by: .................. Rudy Hendriks


EARL C. SHIRLEY, P.E.
Chief, Office of Transportation
Materials & Research

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This study was performed in cooperation with the Federal Highway Administration, under the research project entitled "Traffic Noise Attenuation as a Function of Ground and Vegetation."

16. ABSTRACT

This interim report presents final results on traffic noise attenuation due to shielding by existing vegetation along highways ("vegetative barriers"), and preliminary findings on excess attenuation by various ground covers. The research project is funded by the Federal Highway Administration and performed by the California Department of Transportation.

Simultaneous noise measurements at various distances were made in shielded and unshielded regions of three vegetative barrier sites bordering freeways. The sites included: 1) oleander, 2) combination of oleander and redwoods, and 3) pine trees, as part of existing landscaping. Observed noise reductions by the vegetation ranged from 0 to 2.7 dBA, and averaged 0.9 dBA. This was not considered significant from a human perception standpoint.

The excess attenuation portion of this project is partially completed. At this time, energy-averaged noise levels ($L_{eq}$) and maximum noise levels ($L_{max}$) have been measured simultaneously by ten microphones (mic's) at distances ranging from 25 to 400 feet and heights of 2.5 to 20 feet. The method of analysis is described and preliminary results indicate that the site parameter $\alpha$, as used in the FHWA Highway Traffic Noise Prediction Model (FHWA-RD-77-108), is much higher than 0.5 used in the model for acoustically absorptive sites.

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## NOTICE

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## CONVERSION FACTORS

English to Metric System (SI) of Measurement

| Quality | English unit | Multiply by | To get metric equivalent |
|---|---|---|---|
| Length | inches (in)or(") | 25.40<br>.02540 | millimetres (mm)<br>metres (m) |
| | feet (ft)or(') | .3048 | metres (m) |
| | miles (mi) | 1.609 | kilometres (km) |
| Area | square inches ($in^2$)<br>square feet ($ft^2$)<br>acres | $6.432 \times 10^{-4}$<br>.09290<br>.4047 | square metres ($m^2$)<br>square metres ($m^2$)<br>hectares (ha) |
| Volume | gallons (gal)<br>cubic feet ($ft^3$)<br>cubic yards ($yd^3$) | 3.785<br>.02832<br>.7646 | litre (l)<br>cubic metres ($m^3$)<br>cubic metres ($m^3$) |
| Volume/Time (Flow) | cubic feet per second ($ft^3/s$ | 28.317 | litres per second 1/s) |
| | gallons per minute (gal/min) | .06309 | litres per second (1/s) |
| Mass | pounds (lb) | .4536 | kilograms (kg) |
| Velocity | miles per hour (mph)<br>feet per second (fps) | .4470<br>.3048 | metres per second (m/s)<br>metres per second (m/s) |
| Acceleration | feet per second squared ($ft/s^2$) | .3048 | metres per second squared ($m/s^2$) |
| | acceleration due to force of gravity (G) ($ft/s^2$) | 9.807 | metres per second squared ($m/s^2$) |
| Density | ($lb/ft^3$) | 16.02 | kilograms per cubic metre ($kg/m^3$) |
| Force | pounds (lbs)<br>(1000 lbs) kips | 4.448<br>4448 | newtons (N)<br>newtons (N) |
| Thermal Energy | British thermal unit (BTU) | 1055 | joules (J) |
| Mechanical Energy | foot-pounds (ft-lb)<br>foot-kips (ft-k) | 1.356<br>1356 | joules (J)<br>joules (J) |
| Bending Moment or Torque | inch-pounds (in-lbs)<br>foot-pounds (ft-lbs) | .1130<br>1.356 | newton-metres (Nm)<br>newton-metres (Nm) |
| Pressure | pounds per square inch (psi)<br>pounds per square foot (psf) | 6895<br>47.88 | pascals (Pa)<br>pascals (Pa) |
| Stress Intensity | kips per square inch square root inch (ksi$\sqrt{in}$) | 1.0988 | mega pascals$\sqrt{metre}$ (MPa $\overline{m}$) |
| | pounds per square inch square root inch (psi$\sqrt{in}$) | 1.0988 | kilo pascals$\sqrt{metre}$ (KPa $\overline{m}$) |
| Plane Angle | degrees (°) | 0.0175 | radians (rad) |
| Temperature | degrees fahrenheit (F) | $\frac{+F - 32}{1.8} = +C$ | degrees celsius (°C) |
| Concentration | parts per million (ppm) | 1 | milligrams per kilogram (mg/kg) |

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* Bob Dawson and Dick Wood for their assistance in computer analysis of the field data.

Without their assistance this project would not have been at this interim stage. Their continued support to bring this project to a successful conclusion is greatly appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

## LIST OF TABLES

## INTRODUCTION AND OBJECTIVES

This interim report presents partial preliminary and final results of a Federal Highway Administration (FHWA) funded research project titled: "Traffic Noise Attenuation as a Function of Ground and Vegetation." This research project focusses on two separate mechanisms of traffic noise attenuation provided by site characteristics:

1. excess attenuation afforded by various ground covers as functions of distances up to 400 feet from traffic sources and of heights up to 20 feet above the ground.

2. shielding by shrubbery and trees of various thicknesses and density typically used in landscaping along highways.

Due to a variety of reasons and unexpected problems mentioned in the quarterly reports, the project has run behind schedule. Some of the causes will be discussed in this report to the extent that they affect the final direction or outcome of the project. Meanwhile, some interesting early results and data trends have surfaced in the preliminary data analysis.

For these reasons, the author feels that an interim report is justified to fulfill the following three objectives:

1. to provide a status report of the project.

2. to present some interesting preliminary results.

3. to discuss some changes from the original proposal and new directions to proceed in.

## BACKGROUND

In 1981, the Office of Transportation Laboratory (now changed to the Office of Transportation Materials & Research) of the California Department of Transportation (Caltrans) completed a federally-funded research project (1) evaluating noise barriers. One of the objectives of that study was to compare FHWA noise prediction and barrier design procedures (2) with controlled field measurements. The research results pointed out that the FHWA model overpredicted noise levels by an average of 3 to 4 dBA.

When comparing model results with measurements, the differences showed a tendency to increase with distance. Generally, within 50 feet or less from the source, the model predictions were about 1.5 to 2 dBA higher than the measurements. At distances up to 300 feet these differences increased by several more dBA.

The offset at lesser distances hinted that the error might have been partially caused by using the National Reference Energy Mean Emission Levels in the model. Subsequent research confirmed this suspicion and resulted in the California Vehicle Noise (Calveno) Emission Levels (3). These were approved by the FHWA for use in California. In 1985 the speed dependent curves were implemented for use by Caltrans.

The implementation of the Calveno curves generally lowered predicted noise levels by 1.5 to 2 dBA and improved the agreement between measured and calculated noise levels significantly. Noise levels predicted for receivers near highways began to agree closely with noise measurements taken at these receivers. Further from the source, however, the model still tended to overpredict, although less than before.

The indication that the model overpredictions increased with distance from the source suggested that the attenuation rates used in the model were not high enough. These rates adjust noise levels calculated at a reference distance of 15 meters (50 feet) to a distance of interest. In the model, the attenuation rates are constant for any distance (2).

Distance attenuation rates as used in the FHWA model consist of two parts: 1) geometric spreading and 2) ground absorption or excess attenuation (2).

Geometric spreading describes the manner in which the sound wave fronts radiate outward from a sound source. For a line source, this "spreading" of wave fronts takes on a cylindrical form. The ever increasing area of the cylinder is proportional to the radial distance from the line source. The acoustical intensity (net energy flowing through a unit area) in decibels changes with distance, in this case by :

$$10 \, Log_{10}(D_o/D)$$

where: $D_o$= a reference distance = 15 meters in FHWA model.
$D$ = distance of interest.

Ground absorption, or excess attenuation is accounted for by a site parameter $\alpha$ . The total attenuation rate including both the cylindrical spreading and ground absorption is expressed as:

$$10 \, Log_{10}(D_o/D)^{1+\alpha}$$

where: $\alpha$ = the site parameter
= 0 for an acoustically hard site (reflective)
= 0.5 for an acoustically soft site (absorptive)

Based on the results of numerous routine Caltrans noise measurements, the Office of Transportation Materials & Research feels that the choice of two values ( either 0 or 0.5 ) for $\alpha$ is too restrictive. The previously mentioned overpredictions by the model were observed for situations when the model dictated the use of $\alpha$ for soft as well as hard sites. This indicates that conditions where $\alpha > 0.5$ are quite common, but are not accounted for by the model.

The purpose of the first part of this research project is to investigate whether or not soft site parameters of 0.5 are adequate and, if not, to determine new values for defined site conditions. The hard site parameter of 0 can be considered a special case of soft site, because the FHWA model implies that this is the lower limit of $\alpha$.

The second part of this research project deals with the attenuation properties of "vegetative barriers" (relatively thin but dense strips of vegetation used primarily for landscaping). During the noise barrier evaluation study (1) attenuations of up to 5 dBA were noticed 3 feet behind a 6-foot-high right-of-way fence covered with thick, dense ivy. The attenuations, however, decreased rapidly to 2 dBA at 20 feet behind the fence. These findings were recorded in field notes, but they were not reported in the study.

Subsequent measurements behind an oleander strip approximately 8 feet high and 17 feet wide paralleling a freeway indicated attenuations ranging from less than 1 dBA to almost 3 dBA, depending on the distance behind the oleander.

In addition to the these somewhat promising observations, Caltrans districts reported complaints from residents near freeways that noise levels increased after trees and shrubs were trimmed by maintenance personnel.

The above events prompted the Office of Transportation Materials & Research to include in this research project the objective of studying the feasibility of reducing freeway noise levels by landscaping in situations requiring only slight noise reductions. If feasible, Caltrans would have an attractive alternative to constructing costly noise barriers in borderline cases; attractive from an aesthetic as well as cost-effective point of view.

This portion of the study has been completed and the final results and conclusions will be presented in this report. No further work is anticipated on "vegetative barrier" research.

In addition to the vegetative findings, some preliminary results and conclusions of the ground attenuation portion of this research project will be presented in this interim report.

## CONCLUSIONS

### Vegetative Barriers.

A comparison of normalized simultaneous noise measurements at shielded and unshielded portions of three sites of different types and combinations of shrubs and trees indicated shielded/unshielded differences of 0 - 2.7 dBA, depending on site and microphone locations. The 2.7 dBA reduction was measured at one site only, and then at one microphone location. The mean reduction for all locations was 0.9 dBA. At least seven noise measurements were taken at each microphone location.

The vegetation types tested included:

* Combination of oleander and redwoods (Site V-1)
* Oleander (Site V-2)
* Pine trees (Site V-3)

The ranges and means of noise reductions due to vegetation by site are:

* Site V-1 - Range: 0.3 to 0.8 dBA; Mean: 0.5 dBA
* Site V-2 - Range: 0.7 to 2.7 dBA; Mean: 1.7 dBA
* Site V-3 - Range: 0.0 to 1.0 dBA; Mean: 0.5 dBA

* Mean Reduction for All Sites combined: 0.9 dBA

The variations of noise reductions at each site were a function of distance behind the vegetative barrier.

With the obvious exception of the 0 dBA difference, all measured differences were statistically significant at a significance level of 0.05. However, statistical significance does not necessarily mean significance in terms of human perception. As a matter of fact, traffic noise reductions of less than 3 dBA can generally not be perceived. The noise reductions observed in this part of the project can therefore not be termed significant from a human perspective.

The Office of Transportation Materials and Research therefore concludes that the use of vegetation is not an effective measure to reduce highway noise on a <u>routine</u> basis. However, for the purposes of meeting specific design noise levels or noise standards, oleander or equivalent shrubs may be of some value in borderline cases when there is sufficient right-of-way available to plant a 15 to 20 foot wide strip. If allowed to to grow to a height of 8 feet with sufficient density, the shrubs should provide an average noise attenuation of 1 to 2 dBA.

The data presented in this report also implies that trimming or removal of shrubs and trees along highways by maintenance or construction personnel does not cause perceivable increases in noise levels to residences originally shielded by the vegetation.

<u>Ground Attenuation Rates</u>.

Preliminary findings indicate that the site parameter $\alpha$ should be greater than the recommended value of 0.5 for soft sites in many instances. An analysis of more than 300 single vehicle passes at 4 sites showed the following average $\alpha$'s for distances of 50 to 200 feet from the source at receiver heights of 5 feet:

| | |
|---|---|
| Autos: | 1.6 |
| Medium Trucks: | 1.4 |
| Heavy Trucks: | 1.1 |

The differences in $\alpha$'s between the three vehicle groups were probably due to the differences in source heights. Noise from higher sources such as heavy trucks, are less affected by ground absorption than noise generated lower to the ground.

The sites were flat and open, without obstacles or reflective surfaces. They ranged from a field with short weeds (3 to 12 inches) to a plowed field with 6 inch furrows, to fields with tall weeds (2 feet) and desert sagebrush.

The site parameters were calculated from two types of measurements of single vehicle passes: time averaged $L_{EQ}$'s and instantaneous $L_{MAX}$'s. After normalizing the $L_{EQ}$ measurements from finite to infinite roadway, the $\alpha$'s of $L_{EQ}$'s were found to be a fairly constant 0.4 higher than those derived from instantaneous measurements for each event. The $\alpha$'s were calculated with the assumptions of perfect line source propagation for the $L_{EQ}$ measurements and perfect point source propagation for the $L_{MAX}$ measurements. The differences between the $\alpha$'s may be due to flaws in these assumptions.

Large variations were found in the noise data. These may be attributed to varying wind speeds and directions during measurements.

## RECOMMENDATIONS

In this interim stage, the Office of Transportation Materials & Research makes the following recommendations:

1. Discontinue further research in the vegetative barrier portion of this project.

2. Vegetation should not be used as a routine highway traffic noise control measure. In borderline cases a greenbelt of oleander may be used to reduce average highway noise levels by 1 to 2 dBA to conform to noise standards or noise abatement criteria. A sufficient amount of right-of-way must be available, however, to incorporate an oleander strip of 15 to 20 feet in width between the shoulder and right-of-way. The oleander must be sufficiently dense (highway generally not visible from receiver location except for some isolated small areas) and at least 8 feet high.

3. Vegetation may still be effectively incorporated in conventional noise barrier designs or used for shielding traffic from direct view, primarily for aesthetic reasons. The 1981 noise barrier evaluation study (1) showed some evidence that highway noise accompanied by visual contact of traffic was more objectionable than noise by itself.

4. At least two or three additional sites should be selected for ground attenuation measurements. These sites should incorporate multilane highways to check the single vehicle pass-by technique used up to the present. The analysis of data already gathered should be continued for different microphone distances and heights.

5. Correlations should also be investigated between attenuation rates and the crosswind direction (+ or -) with

respect to the highway and crosswind speed. Methods to normalize noise measurements to zero wind conditions should be investigated, in order to eliminate large data variations.

# IMPLEMENTATION

The final conclusions regarding vegetative barriers do not require an immediate change in present Caltrans policies. Further consultation with the Office of Project Planning and Design and other pertinent departments may result in a future policy or procedure change regarding the before mentioned possible use of oleander "barriers" in borderline cases.

Formal implementation of the interim findings concerning ground attenuation is not warranted at this time, due to their incomplete nature.

Immediately following approval of the final report by the FHWA, pertinent recommendations published at that time will be incorporated in the Caltrans versions of traffic noise prediction methods and noise barrier design procedures.

Memorandums will be sent to all Caltrans districts to advise project development and environmental branches of any changes in methods and procedures.

The Office of Transportation Materials & Research will coordinate with The Office of Project Planning and Design concerning publishing any necessary revisions of revisions of Chapter 1100 of the Caltrans Highway Design Manual.

## BENEFITS

Preliminary findings presented in this report suggest that in many instances the attenuation rates presently used are too low, resulting in the FHWA model predicting higher noise levels than actually occur.

The current Caltrans practice of "calibrating" the model - or adjusting the model predictions to real world conditions through key measurements of traffic and noise - adequately solves the problem for Type II projects as defined in FHPM 7-7-3 (4). Type II projects are retrofit construction of noise barriers along existing highway or freeway alignments and profiles.

For new construction (Type I) projects, however, the accuracy of noise predictions depend entirely on the accuracy of the model without the benefit of calibration. Higher predicted than actual noise levels could result in construction of acoustically overdesigned noise barriers or barriers that were not required.

If present trends continue, this research project may conclude that the value 0.5 for a soft site alpha is too low. Until this project is completed, however, there is no way to predict with any degree of confidence what value to use in lieu of 0.5 and to describe the ground conditions for any of the new value(s) that might be proposed.

The vegetative barrier portion of this study may be used to address noise complaints due to trimming shrubbery by Caltrans Maintenance, or due to outright removal of vegetation in clearing and grubbing phases of construction projects.

## VEGETATIVE BARRIER MEASUREMENTS

### Sites, Instrumentation, and Methods.

Three vegetative barrier sites were used in this study (Sites V-1 through V-3). Each site consisted of two regions: the shielded and unshielded regions. "Shielded" refers to that portion of the site that was visually (and hopefully acoustically) shielded from the highway traffic by the barrier's vegetative mass. Conversely, the "unshielded" portion referred to an adjacent area that was not shielded from the traffic source.

The sites were selected using several qualitative criteria, the most important of which were (not necessarily in order of importance):

* shielded portions to have a vegetative barrier of sufficient vegetative mass (includes both density and width or thickness) and height.

* unshielded portions to be open without any significant obstacles or reflected surfaces.

* approximate site equivalency (similar site geometries and ground covers) between shielded and unshielded portions.

* approximate source equivalency (same traffic passing the shielded and unshielded array of mic's, with roughly the same lane distributions).

* sufficient amount of traffic to lessen chances of contamination by background noise levels.

* sufficient variety of distances available for noise

measurements.

* ability to set up two arrays of microphones, one in the shielded and one in the unshielded region, at the same distances and heights relative to the source highway edge of pavement (EP).

Depending on the site, either 3 or 4 microphones (mic's) were set up in each region in a line perpendicular to the highway, at various distances from the EP. At the shielded half of each site, the mic positions were labeled "A"; here, all but one mic were shielded by the vegetative barrier. The only unshielded mic was labeled control mic "A", or "CA". The shielded mic's were numbered 1A, 2A, etc.

At the sites' unshielded half, the mic's were designated "CB", 1B, 2B, etc. The mic's were positioned at the same distance and height relative to the EP as their "A" mic counterparts, (i.e. mic "CA" and "CB" were at the same height and distance from EP, mic 1A was similarly matched with mic 1B, etc.)

Noise data from mic's "CA" and "CB" were later used to "normalize" the "A" and "B" mic's in the noise comparisons of the shielded and unshielded portions at easch site.

Figures A-1 through A-9 show vicinity maps, layouts, cross sections, and mic positions at each site, and details about the vegetative barriers (Appendix A).

All sound level meters (SLM) used in this study met the requirements of Type I Precision SLM per ANSI S1.4, 1983 (5). The following instruments were used in this study:

* 6 Bruel & Kjaer (B&K) 2218 Precision SLM with B&K 4165 mic's.

* 2 B&K 4426 Noise Level Analyzer with B&K 4165 mic's.

* 1 B&K 4230 Calibrator.

All SLM's and analyzers were field calibrated before and after each series of noise measurements. In addition to the field calibration, all the Office of Transportation Materials & Research's noise equipment is calibrated annually in the Office's laboratory as part of its Quality Assurance Program (QAP). This program calibrates all Caltrans' noise monitoring equipment. Procedures under the QAP are traceable to the National Bureau of Standards (NBS) in Washington, D.C. via two B&K 4160 Laboratory Standard Microphones which are calibrated annually by NBS.

Traffic volumes were videotaped and later counted in the laboratory. The purpose of these traffic measurements was to confirm that all the noise measured at each site indeed came from the highway and that no significant contamination by local noise ocurred. The FHWA model (2) was used for this purpose, with California Vehicle Noise (Calveno) Emission Levels (3).

Wind speed and direction were measured by a Belfort Instrument Co. hand held anemometer.

The "A" and "B" mic's at each site measured highway traffic noise simultaneously for a minimum of 15 minutes for each run. A minimum of 7 runs were measured at each site, during which traffic was videotaped and prevailing wind conditions observed and recorded.

## Measurement Results.

Tables 1 (3 pages) and 2 show the results of the noise measurements, traffic counts, and meteorological observations at the three vegetative barrier sites V-1, V-2, and V-3.

The traffic flow rates in vehicles per hour were expanded by multiplying the videotaped 15 minute traffic counts by 4. The three vehicle groups shown (heavy trucks, medium trucks, and autos) are defined in the FHWA model (2).

Average traffic speeds were estimated from free flowing conditions observed by the author on previous travels on these routes.

Equivalent lane distances were calculated for each direction of traffic (2) from site survey data.

The traffic flow rates, speeds, and the equivalent lane distances were later used in the data analysis.

## Data Analysis.

The first step in analyzing the measured data was to ascertain that the measured noise levels could entirely be explained by the highway traffic. If this were to be true the chances of contamination by other than highway noise sources would be small. The significance of this is obvious: contamination from local sources could dilute any shielding effects provided by the vegetative barrier.

The traffic information shown in Table 1 was used to predict noise levels from the highway at the unshielded portions of the three sites. The FHWA model with California Vehicle Noise Emission Levels was used for the predictions (2,3). The FHWA model cannot adequately account for the shielding of

TABLE 1
NOISE AND TRAFFIC MEASUREMENTS AT VEGETATION BARRIER SITES

SITE V-1
Date of Measurements: February 5, 1987

| Run No. | Times: Begin-End | Microphones - Leq, dBA "CA" | "1A" | "2A" | "3A" | "CB" | "1B" | "2B" | "3B" |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12:35-12:55 | 78.2 | 74.4 | 72.2 | 70.0 | 76.9 | 73.5 | + | + |
| 2 | 13:00-13:20 | 78.1 | 74.3 | 71.9 | 69.8 | 76.9 | 73.5 | 71.4 | 67.4 |
| 3 | 13:30-13:50 | 78.0 | 74.7 | 72.4 | 69.8 | 76.7 | 73.4 | 71.3 | 67.3 |
| 4 | 13:55-14:15 | 77.9 | 74.3 | 71.9 | 69.7 | 77.0 | 73.7 | 71.6 | 68.8 |
| 5 | 14:20-14:40 | 78.6 | 74.9 | 72.3 | 70.1 | 77.3 | 73.9 | 71.7 | 68.8 |

(Traffic Not Counted During Above Measurements)

Date of Measurements: March 15, 1989

| Run No. | Times: Begin-End | Microphones - Leq, dBA "CA" | "1A" | "2A" | "3A" | "CB" | "1B" | "2B" | "3B" |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11:00-11:15 | 79.3 | 75.2 | 72.4 | 67.9 | 78.3 | 74.8 | 72.5 | 68.8 |
| 2 | 11:20-11:35 | 78.9 | 74.8 | 72.0 | 67.4 | 78.1 | 74.6 | 72.2 | 68.4 |
| 3 | 11:40-11:55 | 79.1 | 75.2 | 72.4 | 68.1 | 78.0 | 74.4 | 72.1 | 68.4 |
| 4 | 12:00-12:15 | 79.3 | 75.1 | 72.1 | 67.8 | 77.9 | 74.1 | 71.7 | 67.7 |
| 5 | 12:20-12:35 | 78.9 | 75.0 | 72.0 | 67.4 | 78.0 | 74.3 | 72.0 | 68.4 |
| 6 | 12:40-12:55 | 79.0 | 75.0 | 72.0 | 67.7 | 77.9 | 74.1 | 71.9 | 68.0 |
| 7 | 13:00-13:15 | 78.8 | 74.8 | 71.7 | 67.1 | 77.9 | 74.1 | 71.8 | 67.8 |

| Run No. | Times Begin-End | Traffic Flow Rate (Vehicles/Hour)# E/B (Near) Lanes Autos | M.Trks | H.Trks | W/B (Far) Lanes Autos | M.Trks | H.Trks |
|---|---|---|---|---|---|---|---|
| 1 | ( S A M E | 1788 | 74 | 222 | 1660 | 70 | 210 |
| 2 | | 2288 | 62 | 186 | 1676 | 64 | 192 |
| 3 | | 2972 | 78 | 234 | 1636 | 60 | 180 |
| 4 | A S | 1780 | 63 | 189 | 2144 | 66 | 198 |
| 5 | | 2036 | 60 | 180 | 1948 | 50 | 200 |
| 6 | | 2004 | 66 | 198 | 1848 | 47 | 141 |
| 7 | A B O V E ) | 2364 | 51 | 153 | 1720 | 42 | 126 |
| | All Runs | Average Speeds: 60 MPH | | | | | |

| Mic. No.'s | Equivalent Lane Distances@, Feet 4 E/B Lanes Autos & M.Trks | E/B Lanes 3&4 Heavy Trucks | 4 W/B Lanes A, MT, and HT | Alpha* |
|---|---|---|---|---|
| "CA" & "CB" | 55 | 45 | 126 | 0 |
| "1A" & "1B" | 84 | 73 | 154 | 0.5 |
| "2A" & "2B" | 109 | 98 | 174 | 0.5 |
| "3A" & "3B" | 144 | 133 | 214 | 0.5 |

NOTES: + No Data due to equipment malfunction.
# Autos, Medium Trucks, and Heavy Trucks as defined in (2).
@ Equivalent Lane Distances calculated per FHWA RD-77-108 (2).
* Site Parameter Alpha per FHWA RD-77-108 (2).

TABLE 1 (Continued)
NOISE AND TRAFFIC MEASUREMENTS AT VEGETATION BARRIER SITES

SITE V-2
Date of Measurements: October 9, 1981
(Previous Unpublished Data)

| Run No. | Times: Begin-End | Microphones - Leq, dBA "CA" | "1A" | "2A" | "CB" | "1B" | "2B" |
|---|---|---|---|---|---|---|---|
| 1&2 | 13:00-13:30 &13:45-14:15 | 81.6 | 78.2 | 71.9 | 81.1 | 78.3 | 73.9 |

| Run No. | Times: Begin-End | Traffic Flow Rate (Vehicles/Hour)# S/B (Near) Lanes Autos | M.Trks | H.Trks | N/B (Far) Lanes Autos | M.Trks | H.Trks |
|---|---|---|---|---|---|---|---|
| 1&2 | Same as Above | 492 | 62 | 146 | 500 | 60 | 170 |

Average Speeds: 65 MPH

Date of Measurements: March 17, 1989

| Run No. | Times: Begin-End | Microphones - Leq, dBA "CA" | "1A" | "2A" | "CB" | "1B" | "2B" |
|---|---|---|---|---|---|---|---|
| 1 | 10:15-10:30 | 81.8 | 78.1 | 72.2 | 82.1 | 79.4 | 75.5 |
| 2 | 10:35-10:50 | 81.6 | 78.0 | 71.8 | 82.0 | 79.2 | 75.1 |
| 3 | 10:55-11:10 | 81.1 | 78.1 | 71.9 | 81.6 | 78.9 | 74.9 |
| 4 | 11:15-11:30 | 82.0 | 78.6 | 72.3 | 82.2 | 79.4 | 75.4 |
| 5 | 11:35-11:50 | 80.2 | 77.0 | 70.4 | 80.7 | 78.0 | 73.8 |
| 6 | 11:55-12:10 | 81.0 | 77.4 | 71.0 | 81.0 | 78.3 | 74.2 |
| 7 | 12:15-12:30 | 81.1 | 77.8 | 71.5 | 81.2 | 78.5 | 74.5 |

| Run No. | Times: Begin-End | Traffic Flow Rate (Vehicles/Hour)# S/B (Near) Lanes Autos | M.Trks | H.Trks | N/B (Far) Lanes Autos | M.Trks | H.Trks |
|---|---|---|---|---|---|---|---|
| 1 | ( S A M E | 1036 | 68 | 120 | 788 | 44 | 176 |
| 2 | | 800 | 44 | 136 | 864 | 44 | 144 |
| 3 | | 880 | 52 | 116 | 924 | 12 | 160 |
| 4 | A S | 912 | 48 | 148 | 1064 | 76 | 148 |
| 5 | | 844 | 36 | 92 | 1164 | 32 | 120 |
| 6 | | 780 | 68 | 136 | 900 | 64 | 120 |
| 7 | A B O V E ) | 868 | 72 | 156 | 820 | 72 | 140 |
| All Runs | | Average Speeds: 65 MPH | | | | | |

| Mic. No.'s | Equivalent Lane Distances@, Feet 2 S/B Lanes Autos & M.Trks | CL S/B Lane 2 Heavy Trucks | 2 N/B Lanes A, MT, and HT | Alpha* |
|---|---|---|---|---|
| "CA" & "CB" | 24 | 19 | 89 | 0 |
| "1A" & "1B" | 46 | 41 | 110 | 0 |
| "2A" & "2B" | 87 | 81 | 151 | 0 |

NOTES: # Autos, Medium Trucks, and Heavy Trucks as defined in (2).
@ Equivalent Lane Distances calculated per FHWA RD-77-108 (2).
* Site Parameter Alpha per FHWA RD-77-108 (2).

TABLE 1 (Continued)
NOISE AND TRAFFIC MEASUREMENTS AT VEGETATION BARRIER SITES

SITE V-3

Date of Measurements: March 22, 1989

| Run No. | Times: Begin-End | Microphones - Leq, dBA "CA" | "1A" | "2A" | "CB" | "1B" | "2B" |
|---|---|---|---|---|---|---|---|
| 1 | 10:00-10:15 | 73.7 | 64.8 | 61.1 | 74.0 | 66.4 | 61.8 |
| 2 | 10:20-10:35 | 73.4 | 64.8 | 61.6 | 73.7 | 66.5 | 62.0 |
| 3 | 10:40-10:55 | 74.2 | 65.3 | 62.0 | 74.5 | 67.1 | 62.4 |
| 4 | 11:00-11:15 | 73.6 | 65.4 | 62.1 | 73.9 | 66.5 | 61.9 |
| 5 | 11:20-11:35 | 71.9 | 63.9 | 60.2 | 72.2 | 64.5 | 59.9 |
| 6 | 12:00-12:15 | 74.6 | 66.6 | 63.2 | 75.0 | 67.8 | 63.1 |
| 7 | 12:20-12:35 | 73.1 | 65.0 | 62.8 | 73.3 | 66.2 | 62.3 |

| | | Traffic Flow Rate (Vehicles/Hour)# | | | | | |
|---|---|---|---|---|---|---|---|
| | | S/B (Near) Lanes | | | N/B (Far) Lanes | | |
| Run No. | Times: Begin-End | Autos | M.Trks | H.Trks | Autos | M.Trks | H.Trks |
| 1 | ( S A M E | 332 | 4 | 44 | 236 | 12 | 100 |
| 2 | | 236 | 12 | 68 | 272 | 12 | 72 |
| 3 | | 240 | 0 | 84 | 316 | 20 | 88 |
| 4 | A S | 300 | 4 | 60 | 320 | 12 | 84 |
| 5 | | 192 | 28 | 28 | 324 | 8 | 84 |
| 6 | | 292 | 12 | 92 | 308 | 12 | 100 |
| 7 | A B O V E ) | 324 | 12 | 44 | 308 | 32 | 80 |
| | All Runs | Average Speeds: 65 MPH | | | | | |

| | Equivalent Lane Distances@, Feet | | | |
|---|---|---|---|---|
| | 2 S/B Lanes | CL S/B Lane 2 | 2 N/B Lanes | |
| Mic. No.'s | Autos & M.Trks | Heavy Trucks | A, MT, and HT | Alpha* |
| "CA" & "CB" | 33 | 28 | 117 | 0 |
| "1A" & "1B" | 73 | 67 | 156 | 0.5 |
| "2A" & "2B" | 123 | 117 | 206 | 0.5 |

NOTES: # Autos, Medium Trucks, and Heavy Trucks as defined in (2).
@ Equivalent Lane Distances calculated per FHWA RD-77-108 (2).
* Site Parameter Alpha per FHWA RD-77-108 (2).

TABLE 2

METEOROLOGICAL OBSERVATIONS DURING NOISE MEASUREMENTS

SITE V-1

Date of Measurements : February 5, 1987

(No Meteorological Observations Were Made on this Date)

Date of Measurements: March 15, 1989

| Run No. | Times: Begin-End | Average Wind Speed (Knots)* | Average Wind Direction (Degrees)@ | Estimated Temperature (Deg. F.) | Sky Condition |
|---|---|---|---|---|---|
| 1 | 11:00-11:15 | 4 | 225 | Upper 60's | Clear |
| 2 | 11:20-11:35 | 3 | 200 | \| | \| |
| 3 | 11:40-11:55 | 4 | 225 | \| | \| |
| 4 | 12:00-12:15 | 5 | 225 | \| | \| |
| 5 | 12:20-12:35 | 6 | 245 | \| | \| |
| 6 | 12:40-12:55 | 7 | 255 | V | V |
| 7 | 13:00-13:15 | 5 | 220 | Lower 70's | Clear |

SITE V-2

Date of Measurements: March 17, 1989

| Run No. | Times: Begin-End | Average Wind Speed (Knots)* | Average Wind Direction (Degrees)@ | Estimated Temperature (Deg. F.) | Sky Condition |
|---|---|---|---|---|---|
| 1 | 10:15-10:30 | 2 | 70 | Upper 60's | Mostly Sunny |
| 2 | 10:35-10:50 | 1 | 270 | \| | \| |
| 3 | 10:55-11:10 | 2 | Variable | \| | \| |
| 4 | 11:15-11:30 | 2 | " | \| | \| |
| 5 | 11:35-11:50 | 2 | " | \| | \| |
| 6 | 11:55-12:10 | 1 | " | V | V |
| 7 | 12:15-12:30 | 2 | " | Lower 70's | P'tly Cloudy |

SITE V-3

Date of Measurements: March 22, 1989

| Run No. | Times: Begin-End | Average Wind Speed (Knots)* | Average Wind Direction (Degrees)@ | Estimated Temperature (Deg. F.) | Sky Condition |
|---|---|---|---|---|---|
| 1 | 10:00-10:15 | 3 | 270 | Upper 60's | Clear & Sunny |
| 2 | 10:20-10:35 | 2 | 270 | \| | " " " |
| 3 | 10:40-10:55 | 1 | 270 | \| | " " " |
| 4 | 11:00-11:15 | 1 | 270 | \| | " " " |
| 5 | 11:20-11:35 | 1 | 270 | \| | " " " |
| 6 | 12:00-12:15 | 1 | 270 | V | " " " |
| 7 | 12:20-12:35 | 2 | 270 | Lower 70's | " " " |

NOTES:

* 1 Knot = 1.15 MPH

@ Degrees clockwise from reference. Reference = 0 degrees = wind blowing from highway to microphones (perpendicular to highway), 90 deg. & 270 deg. are parallel to highway, and 180 deg. = wind blowing from microphones to highway (perpendicular to highway).

vegetation. The predicted results were therefore only accurate for unshielded portions of the sites, i.e. the "B" mic's.

Table 3 shows a comparison of predicted and measured noise levels at the three sites ("B" mic's only). As can readily be seen, the differences were generally between 0 and 2 dBA or within the normal accuracy of the model. Only 2 of the 70 comparisons showed differences greater than 2 (Site V-1, run 3, mic 2B: + 2.1 dBA, and Site V-3, run 5, mic 2B: +2.7 dBA). The agreement between predicted and measured noise levels is strong evidence that no local contamination of the noise measurements occurred at the microphones.

The next step consisted of normalizing the noise data simultaneously collected at the shielded and unshielded portions of each site. As was mentioned before, this was done via the control mic.'s "CA" and "CB". Although each site was carefully selected so that the shielded and unshielded portions were acoustically equivalent, small differences between control mic's still existed. These differences can be eliminated by setting the noise levels at one control mic equal to the other's and making the necessary corrections at the remaining mic's.

Another way to normalize "A" and "B" mic's is to compare the differences beteen control mic and other mic's, i.e. CA - 1A vs CB - 1B, CA - 2A vs CB - 2B, etc. This method, shown in Table 4, was used in the analysis. Since the "A" mic's are shielded (except for "CA"), one would expect greater difference between CA and 1A than CB and 1B, etc. The difference of these differences then can be attributed to the shielding by the vegetation. Table 4 (2 pages) presents these comparisons. In all but one instances the CA - iA values were greater than the CB - iB values (where i = 1,2, or 3), indicating a shielding effect from the vegetation barriers in almost all cases.

TABLE 3

COMPARISONS OF PREDICTED* VS MEASURED NOISE LEVELS (Leq, dBA) AT UNSHIELDED PORTIONS OF VEGETATION BARRIER SITES.

SITE V-1

| | MIC "CB" | | | MIC "1B" | | | MIC "2B" | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Pred. | Meas. | P - M | Pred. | Meas. | P - M | Pred. | Meas. | P - M |
| 1 | 79.1 | 78.3 | +0.8 | 74.9 | 74.8 | +0.1 | 73.4 | 72.5 | +0.9 |
| 2 | 79.0 | 78.1 | +0.9 | 74.8 | 74.6 | +0.2 | 73.3 | 72.2 | +1.1 |
| 3 | 79.8 | 78.0 | +1.8 | 75.6 | 74.4 | +1.2 | 74.0 | 72.1 | +2.1 |
| 4 | 78.9 | 77.9 | +1.0 | 74.7 | 74.1 | +0.6 | 73.2 | 71.7 | +1.5 |
| 5 | 78.9 | 78.0 | +0.9 | 74.7 | 74.3 | +0.4 | 73.2 | 72.0 | +1.2 |
| 6 | 78.9 | 77.9 | +1.0 | 74.6 | 74.1 | +0.5 | 73.1 | 71.9 | +1.2 |
| 7 | 78.6 | 77.9 | +0.7 | 74.3 | 74.1 | +0.2 | 72.8 | 71.8 | +1.0 |

| | MIC "3B" | | |
|---|---|---|---|
| Run No. | Pred. | Meas. | P - M |
| 1 | 69.7 | 68.8 | +0.9 |
| 2 | 69.6 | 68.4 | +1.2 |
| 3 | 70.3 | 68.4 | +1.9 |
| 4 | 69.5 | 67.7 | +1.8 |
| 5 | 69.5 | 68.4 | +1.1 |
| 6 | 69.3 | 68.0 | +1.3 |
| 7 | 69.0 | 67.8 | +1.2 |

SITE V-2

| | MIC "CB" | | | MIC "1B" | | | MIC "2B" | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Pred. | Meas. | P - M | Pred. | Meas. | P - M | Pred. | Meas. | P - M |
| 1 | 80.7 | 82.1 | -1.4 | 78.0 | 79.4 | -1.4 | 75.8 | 75.5 | +0.3 |
| 2 | 80.4 | 82.0 | -1.6 | 77.8 | 79.2 | -1.4 | 75.4 | 75.1 | +0.3 |
| 3 | 80.3 | 81.6 | -1.3 | 77.5 | 78.9 | -1.4 | 75.4 | 74.9 | +0.5 |
| 4 | 80.9 | 82.2 | -1.3 | 78.3 | 79.4 | -1.1 | 75.9 | 75.4 | +0.5 |
| 5 | 79.7 | 80.7 | -1.0 | 77.2 | 78.0 | -0.8 | 74.9 | 73.8 | +1.1 |
| 6 | 80.4 | 81.0 | -0.6 | 77.9 | 78.3 | -0.4 | 75.4 | 74.2 | +1.2 |
| 7 | 80.9 | 81.2 | -0.3 | 78.3 | 78.5 | -0.2 | 75.9 | 74.5 | +1.4 |

SITE V-3

| | MIC "CB" | | | MIC "1B" | | | MIC "2B" | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Pred. | Meas. | P - M | Pred. | Meas. | P - M | Pred. | Meas. | P - M |
| 1 | 74.7 | 74.0 | +0.7 | 67.3 | 66.4 | +0.9 | 63.4 | 61.8 | +1.6 |
| 2 | 75.1 | 73.7 | +1.4 | 67.7 | 66.5 | +1.2 | 63.6 | 62.0 | +1.6 |
| 3 | 75.7 | 74.5 | +1.2 | 68.3 | 67.1 | +1.2 | 64.2 | 62.4 | +1.8 |
| 4 | 75.0 | 73.9 | +1.1 | 67.7 | 66.5 | +1.2 | 63.7 | 61.9 | +1.8 |
| 5 | 73.7 | 72.2 | +1.5 | 66.4 | 64.5 | +1.9 | 62.6 | 59.9 | +2.7 |
| 6 | 76.3 | 75.0 | +1.3 | 68.9 | 67.8 | +1.1 | 64.7 | 63.1 | +1.6 |
| 7 | 74.7 | 73.3 | +1.4 | 67.4 | 66.2 | +1.2 | 63.4 | 62.3 | +1.1 |

* Predictions per FHWA 77-RD-108 with California Vehicle Noise (Calveno) Emission Levels FHWA/CA/TL-87/03 (2,3).

TABLE 4
STATISTICAL COMPARISONS
BETWEEN SHIELDED AND UNSHIELDED PORTIONS OF VEGETATION BARRIER SITES

SITE V-1

Date of Measurements: Februay 5, 1989

| Run No. | Control Mic.'s "CA" & "CB" Minus Remaining Mic.'s, dBA | | | | | |
|---|---|---|---|---|---|---|
| | Shielded "CA"-"1A" | Unshielded "CB"-"1B" | Shielded "CA"-"2A" | Unshielded "CB"-"2B" | Shielded "CA"-"3A" | Unshielded "CB"-"3B" |
| 1 | 3.8 | 3.4 | 6.0 | + | 8.2 | + |
| 2 | 3.8 | 3.4 | 6.2 | 5.5 | 8.3 | 9.5 |
| 3 | 3.3 | 3.3 | 5.6 | 5.4 | 8.2 | 9.4 |
| 4 | 3.6 | 3.6 | 6.0 | 5.4 | 8.2 | 8.2 |
| 5 | 3.7 | 3.4 | 6.3 | 5.6 | 8.5 | 8.5 |
| x | 3.6 | 3.4 | 6.0 | 5.5 | 8.3 | 8.9 |
| s | 0.21 | 0.11 | 0.27 | 0.10 | 0.13 | 0.65 |
| n | 5 | 5 | 5 | 4 | 5 | 4 |
| | $t^* = -2.075$ | | $t^* = -3.825$ | | $t^* = +2.116$ | |
| | $t_{0.05;8} = -1.860$ | | $t_{0.05;7} = -1.895$ | | $t_{0.05;7} = -1.895$ | |
| | Difference IS Signif. | | Difference IS Signif. | | Difference IS Signif, but Opposite from that expected. | |

Date of Measurements: March 15, 1989

| Run No. | Control Mic.'s "CA" & "CB" Minus Remaining Mic.'s, dBA | | | | | |
|---|---|---|---|---|---|---|
| | Shielded "CA"-"1A" | Unshielded "CB"-"1B" | Shielded "CA"-"2A" | Unshielded "CB"-"2B" | Shielded "CA"-"3A" | Unshielded "CB"-"3B" |
| 1 | 4.1 | 3.5 | 6.9 | 5.8 | 11.4 | 9.5 |
| 2 | 4.1 | 3.5 | 6.9 | 5.9 | 11.5 | 9.7 |
| 3 | 3.9 | 3.6 | 6.7 | 5.9 | 11.0 | 9.6 |
| 4 | 4.2 | 3.8 | 7.2 | 6.2 | 11.5 | 10.2 |
| 5 | 3.9 | 3.7 | 6.9 | 6.0 | 11.5 | 9.6 |
| 6 | 4.0 | 3.8 | 7.0 | 6.0 | 11.3 | 9.9 |
| 7 | 4.0 | 3.8 | 7.1 | 6.1 | 11.7 | 10.1 |
| x | 4.0 | 3.7 | 7.0 | 6.0 | 11.4 | 9.8 |
| s | 0.11 | 0.14 | 0.16 | 0.13 | 0.22 | 0.27 |
| n | 7 | 7 | 7 | 7 | 7 | 7 |
| | $t^* = -4.458$ | | $t^* = -12.833$ | | $t^* = -12.154$ | |
| | $t_{0.05;12} = -1.782$ | | $t_{0.05;12} = -1.782$ | | $t_{0.05;12} = -1.782$ | |
| | Difference IS Signif. | | Difference IS Signif. | | Difference IS Signif. | |

NOTES: $t^*$ = calculated from Student's t - Test (see text).
This value was compared to the "critical" t for a level of significance of 0.05 with $(n_1 + n_2 - 2)$ degrees of freedom.
Difference between $\bar{x}_A$ and $\bar{x}_B$ is significant if the calculated t exceeds the critical t in absolute value.

TABLE 4 (Continued)
STATISTICAL COMPARISONS
BETWEEN SHIELDED AND UNSHIELDED PORTIONS OF VEGETATION BARRIER SITES

SITE V-2
Date of Measurements: March 17, 1989

| Run No. | Control Mic.'s "CA" & "CB" Minus Remaining Mic.'s, dBA: Shielded "CA"-"1A" | Unshielded "CB"-"1B" | Shielded "CA"-"2A" | Unshielded "CB"-"2B" |
|---|---|---|---|---|
| 1 | 3.7 | 2.7 | 9.6 | 6.6 |
| 2 | 3.8 | 2.8 | 9.9 | 6.9 |
| 3 | 3.0 | 2.7 | 9.2 | 6.7 |
| 4 | 3.4 | 2.8 | 9.7 | 6.8 |
| 5 | 3.2 | 2.7 | 9.8 | 6.9 |
| 6 | 3.6 | 2.7 | 10.0 | 6.8 |
| 7 | 3.3 | 2.7 | 9.6 | 6.7 |
| x | 3.4 | 2.7 | 9.7 | 6.8 |
| s | 0.25 | 0.05 | 0.26 | 0.11 |
| n | 7 | 7 | 7 | 7 |
| | $t^* = -7.265$ | | $t^* = -27.178$ | |
| | $t_{0.05;12} = -1.782$ | | $t_{0.05;12} = -1.782$ | |
| | Difference IS Signif. | | Difference IS Signif. | |
| 10/9/81 Data: | 3.4 | 2.8 | 9.7 | 7.2 |

SITE V-3
Date of Measurements: March 22, 1989

| Run No. | Control Mic.'s "CA" & "CB" Minus Remaining Mic.'s, dBA: Shielded "CA"-"1A" | Unshielded "CB"-"1B" | Shielded "CA"-"2A" | Unshielded "CB"-"2B" |
|---|---|---|---|---|
| 1 | 8.9 | 7.6 | 12.6 | 12.2 |
| 2 | 8.6 | 7.2 | 11.8 | 11.7 |
| 3 | 8.9 | 7.4 | 12.2 | 12.1 |
| 4 | 8.2 | 7.4 | 11.5 | 12.0 |
| 5 | 8.0 | 7.7 | 11.7 | 12.3 |
| 6 | 8.0 | 7.2 | 11.4 | 11.9 |
| 7 | 8.1 | 7.1 | 10.3 | 11.0 |
| x | 8.4 | 7.4 | 11.6 | 11.9 |
| s | 0.41 | 0.22 | 0.72 | 0.44 |
| n | 7 | 7 | 7 | 7 |
| | $t^* = -5.686$ | | $t^* = 0.940$ | |
| | $t_{0.05;12} = -1.782$ | | $t_{0.05;12} = -1.782$ | |
| | Difference IS Signif. | | Difference NOT Signif | |

NOTES: t* = calculated from Student's t - Test (see text). This value was compared to the "critical" t for a level of significance of 0.05 with ($n_1 + n_2 - 2$) degrees of freedom. Difference between $\bar{x}_A$ and $\bar{x}_B$ is significant if the calculated t exceeds the critical t in absolute value.

The one exception was in the comparison between CA - 3A and CB - 3B values in the Site V-1 data of February 5, 1987 (Table 4). These data showed a reversal of the shielding, indicating an increase of 0.6 dBA at mic 3. However, when averaged with data collected on March 15, 1989, which did show the expected decrease, the average noise reduction was 0.5 dBA.

No direct explanation can be given for the reversal. Local contamination of noise measurements at mic 3A could be one explanation. However, if such contamination were present, it would probably have affected mic's 1A and 2A as well.

Another explanation for the reversal could have been opposite wind directions at the "A" and "B" portions of the Site V-1 (less than a quarter of a mile apart). Wind measurements were usually made at one location to represent the entire site. On the date of the reversal no meteorological measurements were taken. In either case, opposite wind directions at the two locations would have remained undetected. However, it is unlikely that this condition existed over an extended period of almost two hours (counting breaks between the measurements).

The reversal appears somewhat excessive to be explained by normal variations in measurements. However, after careful scrutiny of the measurement results, no obvious abberations could be detected. The February 5, 1987 data at mic's 3A and 3B were therefore accepted and averaged in with the data of March 15, 1989.

With the exception of one, all reductions due to shielding were found to be statistically significant when subjected to a statistical "t"-test with a level of significance = 0.05 (6). The exception was at Site V-3, mic 2 which showed a statistically insignificant reduction of 0.3 dBA. Further examination of the site indicated a 7 foot gap in the vegetative barrier, visible from mic 2, but not mic 1 as shown in Figure A-8 (Appendix A).

Table 5 summarizes all the statistically significant noise reductions due to vegetative shielding. Note that mic 2, Site 3 shows a zero reduction, because of its statistical insignificance. Also summarized on Table 5 is pertinent vegetation information and a subjective "vegetative mass" classification scheme used to report the findings in this report.

Conclusions.

There is a distinction between statistical significance and human significance. The former is a measure determined by the "spread" of the data around the mean (standard deviation) and the number of (noise) samples taken. The latter is determined by human perception of noise. From a human perception standpoint, the reductions ranging from 0 - 2.7 dBA and averaging 0.9 dBA are not significant.

The Office of Transportation Materials & Research therefore concludes that vegetative barriers are not an effective highway noise mitigation measure to be used on a routine basis. However, for the purpose of meeting specific design noise levels or noise standards, oleander or equivalent shrubs may be of some value in borderline cases. Sufficient right-of-way is necessary to plant a 15 to 20 foot wide strip. If allowed to grow to a height of at least 8 feet with a high vegetative mass (see Table 5 for definition) the shrubs should provide an average noise attenuation of 1 to 2 dBA.

The data in Table 5 also implies that trimming or outright removal of shrubs and trees along highways by maintenance or construction personnel does not cause perceivable noise

TABLE 5
NOISE LEVEL REDUCTION DUE TO SHIELDING BY VEGETATION

| Site | Vegetation Types & Description Of Vegetative Mass* | Dimensions | Noise Reduction, dBA @ Distances Behind Vegetation @ Mic.1A | @ Mic.2A | @ Mic.3A |
|---|---|---|---|---|---|
| V-1 | Oleander strip, parallel to fwy, medium Veg. Mass. | 9' high 13' wide | 0.3 dBA @ 10 ft | 0.8 dBA @ 35 ft | 0.5 dBA @ 70 ft |
| | Redwoods, along centerline of oleander strip, equally spaced @ 30' on center. | 50' tall, 20' total spread, (mainly above oleander) | MEAN REDUCTION: 0.5 dBA | | |
| V-2 | Oleander strip, parallel to fwy, high Veg. Mass. | 8' high 17' wide | 0.7 dBA @ 3 ft | 2.7 dBA @ 44 ft | |
| | | | MEAN RED: 1.7 dBA | | |
| V-3 | Pine trees, low to medium Veg. Mass, single line, parallel to fwy, unequally spaced, @ 10'-20' on ctr with some openings (nearest opening of 7' was about 40' from mic.line), branches intertwined. | 40' tall 30' wide (pine boughs were touching the ground) | 1.0 dBA @ 7 ft | 0 dBA @ 57 ft Due to 7'opening nearby, mic. was exposed to direct fwy noise | |
| | | | MEAN RED: 0.5 dBA | | |

NOTES: * Vegetative Mass is defined in this report as a property of the vegetation "barrier" that includes both density and width ("thickness"). A subjective grading system based on visual inspection from the receiver location is used as follows:

High Vegetative Mass = Highway generally not visible through the vegetation except for some isolated small areas.

Medium Vegetative Mass = Portions of the highway faintly visible through the vegetation.

Low Vegetative Mass = Highway clearly visible through the vegetation.

increases to residences that were originally shielded by the vegetation.

On the basis of these findings, no additional research will be done in vegetative barriers as part of this project.

## GROUND ATTENUATION RATE MEASUREMENTS (INTERIM)

### Project Status.

This portion of the research project titled: "Traffic Noise Attenuation as a Function of Ground and Vegetation" is in an interim stage. The project is behind schedule due to a variety of field problems, and increased work loads coupled with reduced staffing. A considerable amount of field work, however, has been completed, and some of these data have been analyzed. The results of these will be reported as preliminary findings. More fieldwork and additional analyses will be required to bring this project to a satisfactory conclusion.

### Research Methodology.

The Background chapter in this report explained the need for refining the distance attenuation rates, preferably in terms of the site parameter $\alpha$ as used in the FHWA model (2).

The intent of this project has always been to provide practical solutions to actual, observed problems in noise prediction parameters. State highway agencies are directed by FHPM 7-7-3 (4) to use traffic noise prediction methods that are consistent with the methodology in the FHWA model. From a practical point of view then it appears reasonable to measure real traffic sources, rather than artificial, and extract from these data the site parameter used in the FHWA model.

By far the majority of traffic noise predictions are made for urban and suburban freeways. These are, after all, the causes of most of the noise complaints in residential areas and need to be addressed most frequently. It seems logical then to measure traffic noise attenuation rates at sites along heavily traveled multi-lane highways. This is, however, not a simple task.

The FHWA model assumes line source propagation for highway traffic noise. A multilane freeway has several line sources simultaneously at different, but known, source-to-receiver distances. Their relative contributions to the measured noise level, however, are unknown. These can, of course, be calculated from measured volumes, mixes and speeds of traffic occupying the line source locations (lanes). Even then, no single fixed centroid can be assumed from which the noise propagates outward at a uniform rate (although this assumption is often made in noise predictions when only directional traffic is available and the lanes in each direction are grouped together).

A single lane with heavy traffic volumes surrounded by flat open fields with homogeneous ground cover and soil conditions would make the ideal site to study attenuation rates. Such a situation would approximate an infinite line source emanating a nearly continuous and high noise level. Assuming that the ambient (background) noise level would be very low, as might easily be expected in this case, the noise attenuation due to distance and ground absorption could be measured over long distances from the roadway. Unfortunately such a situation is not readily (if at all) available.

In order to maintain the single line source aspect of an ideal site, the approach used in this project was to study single vehicle passes on very low volume two-lane highways. If the noise from a passing vehicle is continuously measured over a time interval, the moving point source behaves as a line source (2). A trace of the instantaneous noise levels from the vehicle would, at some point in time, begin to register above the ambient noise as it approaches, increase to a maximum, and decrease again to a point in time when it dips below the background noise.

Figure B-1 in Appendix B shows this situation for a heavy truck at 50 feet from the centerline of travel. The FHWA model (2) was used with California Vehicle Noise (Calveno) Emission Levels. An $\alpha$ of 1.0 (very absorptive site) was assumed in the example. First, the hourly $L_{EQ}$, or $L_{EQ}$(h) was calculated at 49.2 dBA. Note that a proper adjustment was made for the finite roadway segment defined by the location of the vehicle at the beginning of the measurement to its location at the end of the measurement. The segment angles were calculated from the given speed of 55 mph and the elapsed time of the measurement.

The $L_{EQ}$ for the duration of the measurement was calculated next. The result of $L_{EQ}$(105 sec) was 64.6 dBA.

In the example beginning and ending ambients of 34 dBA and 39 dBA respectively, were assumed. Note that the average ambient of 37 dBA did not contribute to the total $L_{EQ}$(105 sec).

In order to measure distance attenuation rates of vehicle noise, measurements need to be made at a minimum of two different distances from the source. The differences between the two measurements - when properly normalized - may then be used to determine $\alpha$. This process is shown in Figures B-2 and B-3, Appendix B. Note that, to arrive at the $\alpha$ via the $L_{EQ}$ measurements, segment adjustments inherent in the noise measurements must be removed first, i.e. the measured data must be normalized from a finite roadway to an infinite roadway.

Since the segment adjustment at each receiver is also a function of $\alpha$ , the process of finding $\alpha$ includes an iterative process of first estimating $\alpha$ , then using the estimate in the segment adjustments. These, in turn, are used to normalize the difference in measurements, $\Delta dBA_{1,2}$(FIN) to the normalized differences, $\Delta dBA_{1,2}(INF)$ as shown by Equation 2, Figure B-2, Appendix B. A new $\alpha$ can then be calculated using Equation 3, Figure B-3, Appendix B, and the next iteration will begin with new segment adjustments, etc.

In this project the process was continued until the difference between the next $\Delta dBA_{1,2}(INF)$ was within 0.1 dBA from the previous one. The final $\alpha$ was then calculated and reported. The first estimate of $\alpha$ can be made in various ways. In this project, it was calculated from the noise level differences between two mic's of interest, or $\Delta dBA_{1,2}(FIN)$. This value was then used as a substitution for $\Delta dBA_{1,2}(INF)$ in Equation 3, Figure B-3, Appendix B.

The site parameter $\alpha$ can also be calculated from differences in instaneous maximum values ($L_{MAX}$). The method of calculation is also outlined in Figure B-3, Appendix B (Equation 4). In theory, the value of $\alpha$ derived from $L_{EQ}$ measurements should match the value of $\alpha$ derived from $L_{MAX}$ measurements, since the methods assume perfect homogeneity of the site, and the measurements of $L_{EQ}$ and $L_{MAX}$ are of the same vehicle, under the same conditions. In reality, however, some of these assumptions may be flawed for the following reasons:

* site may not be perfectly homogeneous; the very small segments incorporating the $L_{MAX}$ values may not be represented by the entire segment of the $L_{EQ}$ values,

* slightly fluctuating meteorology, especially wind speeds and directions, averaged during an entire $L_{EQ}$ measurement may be different than the instantaneous conditions of the $L_{MAX}$ measurement,

* the assumed constant vehicle speed may actually fluctuate somewhat.

* vehicle noise may not propagate by perfect cylindrical spreading as assumed for the $L_{EQ}$ measurements, or by perfect spherical spreading assumed for $L_{MAX}$.

Sites and Instrumentation.

Four sites, labeled G-1 through G-4, have been measured so far. Each site is in flat open terrain surrounding a two-lane rural highway with very low traffic volumes, on the order of one vehicle every few minutes.

Three of the four sites are in California's Central Valley:

* G-1 "Kesterson" is along eastbound State Route (SR)-140, 4 miles northeast of Gustine and the junction of SR-33 and SR-140, at Kesterson Wildlife Refuge. Ground cover: 1 to 2 foot high dense weeds and grasses.

* G-3 "Lemoore" is along westbound SR-198, 11 miles east of Interstate (I)-5. Ground cover: None, plowed field with 6 to 8 inch deep furrows.

* G-4 "Avenue 7" is along eastbound Avenue 7, 13 miles east of Firebaugh, and approximately 15 miles southwest of Madera. Ground cover: 3 to 12 inch high weeds.

Site G-2 was located in a desert region east of the California's Sierra Nevada on the north end of Owen's Valley about 7 miles north of Bishop, along US-6. Ground Cover: 2 to 3 foot high sage brush.

Figure B-4 in Appendix B shows two ideal microphone setups superimposed. These configurations were used at each site. Since only ten sound level meters (SLM) were available, the configuration shown was actually done in two setups. The first setup included typically the 2.5 and 5 foot high mic's at 50, 100, 200, and 400 feet from the center line of vehicle travel, and the 5 and 10 foot high mic at the 25 foot distance. The second setup included the 10 and 20 foot high mic's at 50, 100, 200, and 400 feet, and 5 foot high reference mic's at 50 and 400 feet. The purpose of the latter two mic's was to relate the high mic setup to the low mic setup.

The instruments used for the noise measurements were:

* 6 Bruel & Kjaer (B&K) 2218 Precision SLM with B&K 4165 mic's.

* 3 B&K 4426 Noise Level Analyzers with B&K 4165 mic's.

* 1 B&K 2230 SLM with B&K 4155 mic.

* 1 Datalogger, custom-built for the former Transportation Laboratory; the unit was manufactured by James Cox and Sons, Inc., Colfax, California, and Walt Winter of Engineering Logic, Sacramento, California.

Calibration was performed as described in the Vegetative Barrier portion of this report.

* Wind speed and direction were measured with a Belfort Instrument Co. anemometer mounted on a stand.

* Vehicle speeds were measured with a Rangemaster 715 radar "gun", made by Decatur Electronics, Inc.

Measurements.

Individual vehicle passes were measured from the time their noise traces (measured at the 5 foot high mic at 400 feet) rose over the low and fairly constant ambient noise to the time they disappeared below ambient levels. The times from the beginning to the point closest to the mic's and the total times were recorded, along with the constant speeds measured by radar. This information would later be used to calculate the finite roadway segments discussed previously.

The observer also recorded vehicle types according to the FHWA RD-77-108 definitions, i.e. autos, medium trucks, and heavy trucks (2).

The noise data at the ten mic's were simultaneously recorded by the datalogger; wind speeds and directions were carefully observed during each vehicle pass, and also recorded, as were other environmental conditions such as relative humidity, temperature, sky conditions, and ambient noise (noise "floor"). Two values were recorded for the latter: one for the ambient noise at the beginning, and one for the end of each event. These would later be energy-averaged.

The purpose of recording the ambient noise level was to determine if the $L_{eq}$ measurement at each receiver was contaminated. If the ambient noise level was at least 10 dBA below the $L_{eq}$ measurement the latter would be free of contamination. The 400 foot mic's of a quiet event had obviously the greatest chance of being contaminated.

A total of 541 events (vehicle passes) were measured at four sites as of this writing. Each event provided noise data for up to ten different locations. A far greater amount of sites was anticipated at the start of the project. The actual rate of field measurement, however, was much slower than expected, due to a variety of major and minor problems.

The major problems encountered warrant further discussion for the benefit of other researchers attempting the same research approach.

The advantages of single vehicle measurements have already been discussed. A disadvantage of this method is that measurements can easily be contaminated by extraneous noise sources such as aircraft, even in relatively remote areas. The distance at which the relatively low noise levels can be measured accurately depends greatly on how low the ambient noise level is.

Although the ambient noise levels at the sites in this project were normally low (25 - 35 dBA), the noise measurements were frequently interrupted by distant noise from farm equipment, aircraft overflights, and locally by birds.

In late spring of 1986 an additional noise problem was encountered: mating cicadas. These insects apparently mate in 17 year cycles, during which they are very noisy. Depending on geographic region the 17 year cycles are set one or more years ahead or behind each other. 1986 was apparently the year of the cicada at Kesterson's site G-1. Consequently, many measurements were contaminated and had to be repeated, due to an ambient cicada concert that reached 50 dBA. The normal ambient noise level at this site was about 32 dBA.

Another major problem associated with single vehicle measurements is relating the meteorological observations to the relatively short averaging time of the noise levels (typically 40 seconds). The spatial differences in wind speed and direction, for example, are more pronounced due to the lack averaging time. Consequently, wind speeds and directions can vary greatly from microphone to microphone in a short time span.

In this project, meteorological data were gathered in a single location, compounding the problem with wind variations. However, even if meteorology could have been observed at each mic simultaneously, a wind field constructed from these data would be confusing and difficult to relate to noise levels. The spatial wind fluctuations may have been the cause of observed variability in noise data. A longer averaging time, possible only if streams of vehicles were measured, would yield a more uniform wind field over the region of a site, and therefore less variability in noise data.

The availability of suitable sites is a third major problem, although this is not necessarily limited to single vehicle measurements. Flat, open areas with uniform ground cover or soil properties in regions of low ambient noise, and proper traffic characteristics are a rare luxury!

Finally, the complexity of a setup involving ten simultaneously measuring SLM should not be overlooked as a problem, not only technically, but also logistically. Older equipment tends to perform flawlessly in the laboratory, but is plagued with failure in the field. Also: no matter how carefully the logistics are planned in advance, some detail will inadvertently be omitted; a vital component left in the laboratory; an unanticipated mishap, etc. The amount of time required to set up, calibrate and troubleshoot a complex system leaves less time for measurements.

There are, however, great advantages to employing many instruments simultaneously. The spatial noise "picture" obtained from a complex setup is the most obvious advantage; system calibration, and measurements under same conditions are other advantages. A simpler setup avoids many of the problems of a complex system, at the expense of quality information. Obviously, a fine balance between what is desired and what can be achieved must be sought before deciding on the complexity of the instrument setup.

Preliminary Results, Conclusions, and Recommendations.

The preliminary analysis included noise data for the 50 and 200 foot mic's at a height of 5 feet. The calculated site parameters $\alpha$ for sites G-1, G-2, G-3, and G-4 are listed in Appendix C by event number (ID_NO) and vehicle type for $L_{EQ}$ (ALPHA) and $L_{MAX}$ (PKALPHA). The crosswind component (CWC) for each event is also shown. A positive CWC means a wind blowing from source to receiver (perpendicular to the highway). A negative CWC blows from receiver to source.

The $\alpha$ values are unexpectedly high. FHWA RD-77-108 (2) recommends an average value of 0.5 for absorptive sites. The reference's Appendix A mentions a "reasonable range" of to be between 0 and 1 from hard to "very absorptive". The four sites used in this project were estimated to range from absorptive (G-3 and G-4) to very absorptive (G-1 and G-2). The average $\alpha$ values based on $L_{EQ}$ and $L_{MAX}$ determined in this project by site and vehicle type follows:

TABLE 6

$\alpha$ Values

Determined From 50 and 200 Foot Mic Data

at a Height of 5 Feet

| Site No. | Vehicle Type: Autos | | Medium Trucks | | Heavy Trucks | |
|---|---|---|---|---|---|---|
| | $L_{EQ}$ | $L_{MAX}$ | $L_{EQ}$ | $L_{MAX}$ | $L_{EQ}$ | $L_{MAX}$ |
| G-1 | 2.1 | 1.7 | 1.9 | 1.6 | 1.9 | 1.1 |
| G-2 | 2.1 | 1.7 | 2.0 | 1.6 | 1.4 | 1.0 |
| G-3 | 1.8 | 1.4 | 1.3 | 1.1 | 1.1 | 0.7 |
| G-4 | 1.2 | 0.8 | 1.2 | 0.6 | 0.9 | 0.4 |

These preliminary findings are by no means conclusive, and need to be verified for other distances. The effects of different heights also need to be examined yet. There is, however, a strong indication that an $\alpha$ of 0.5 is not high enough for many soft sites. This would explain the commonly occurring over predictions by the FHWA model, especially at greater distances from the highway.

Another interesting finding is the fairly constant difference between $\alpha$'s derived from $L_{EQ}$ and $L_{MAX}$ data. This difference of about 0.4 to 0.5 does not appear to be site-dependent and may be due to flaws in perfect line and point source assumptions. Once again, other distances need to be examined to shed light on this phenomenon.

The principal investigator of this project intends to validate the preliminary site parameter values for multiple lanes through comparisons of measurements and model predictions using the values based on single vehicle measurements. Multiple lane sites with ground cover comparable to some of the single lane sites will be selected for this purpose. It is expected that two or three such sites will be measured for the remainder of the project, using using less complex instrumentation setups than those used so far.

Further analysis in correlation between noise levels and meteorology will also be examined. Time-averaged observations are expected to correlate better with noise measurements of longer duration (say 15 minutes) than those obtained during the shorter time span of single vehicle noise measurements.

If present data trends continue, the final report will probably recommend using a higher value of $\alpha$ than 0.5 for soft sites. Due to the presently observed variability of noise data it is unlikely that refinements can be made for various types of ground cover as was anticipated at the beginning of this project. However, if, on the basis of strong evidence gathered in this research, a sound recommendation can be made to use a different value of $\alpha$ , this research project will have been successful.

## REFERENCES.


1. Hendriks, R.W., and M.M. Hatano, "Evaluation of Noise Barriers", California Department of Transportation, Office of Transportation Laboratory, FHWA/CA/TL-81/07, June 1981.

2. Barry, T.M., and J.A. Reagan, "FHWA Highway Traffic Noise Prediction Model", Federal Highway Administration, FHWA-RD-77-108, December 1978.

3. Hendriks, R.W., "California Vehicle Noise Emission Levels (Final Report)", California Department of Transportation, Office of Transportation Laboratory, FHWA/CA/TL-87/03, January 1987.

4. Federal-Aid Highway Program Manual, Vol. 7, Ch. 7, Sec. 3, Federal Highway Administration, August 9, 1982.

5. Specification for Sound Level Meters, American National Standards Institute (ANSI), S 1.4 - 1983.

6. Bowker, A.H., and G.J. Lieberman, Engineering Statistics, Second Edition, Prentice-Hall, Inc., 1972.

APPENDIX A

VEGETATIVE SITES:

Vicinity Maps, Layouts and Cross Sections
of Sites V-1, V-2, and V-3
(See Text)

FIGURE A-1-SITE V-1 AND VICINITY

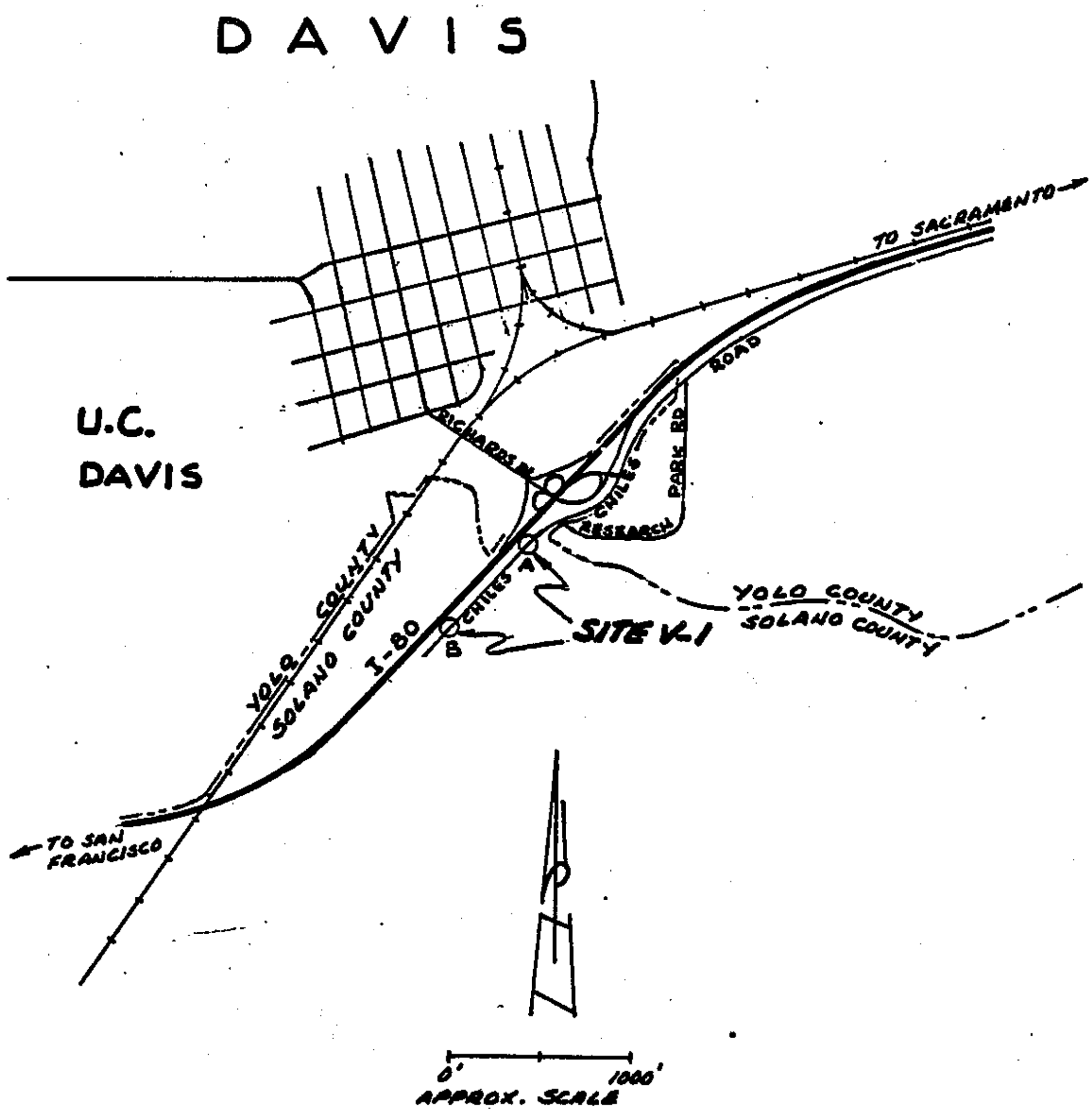


FIGURE A-2 · VEGETATION BARRIER SITE V-1
LAY OUT

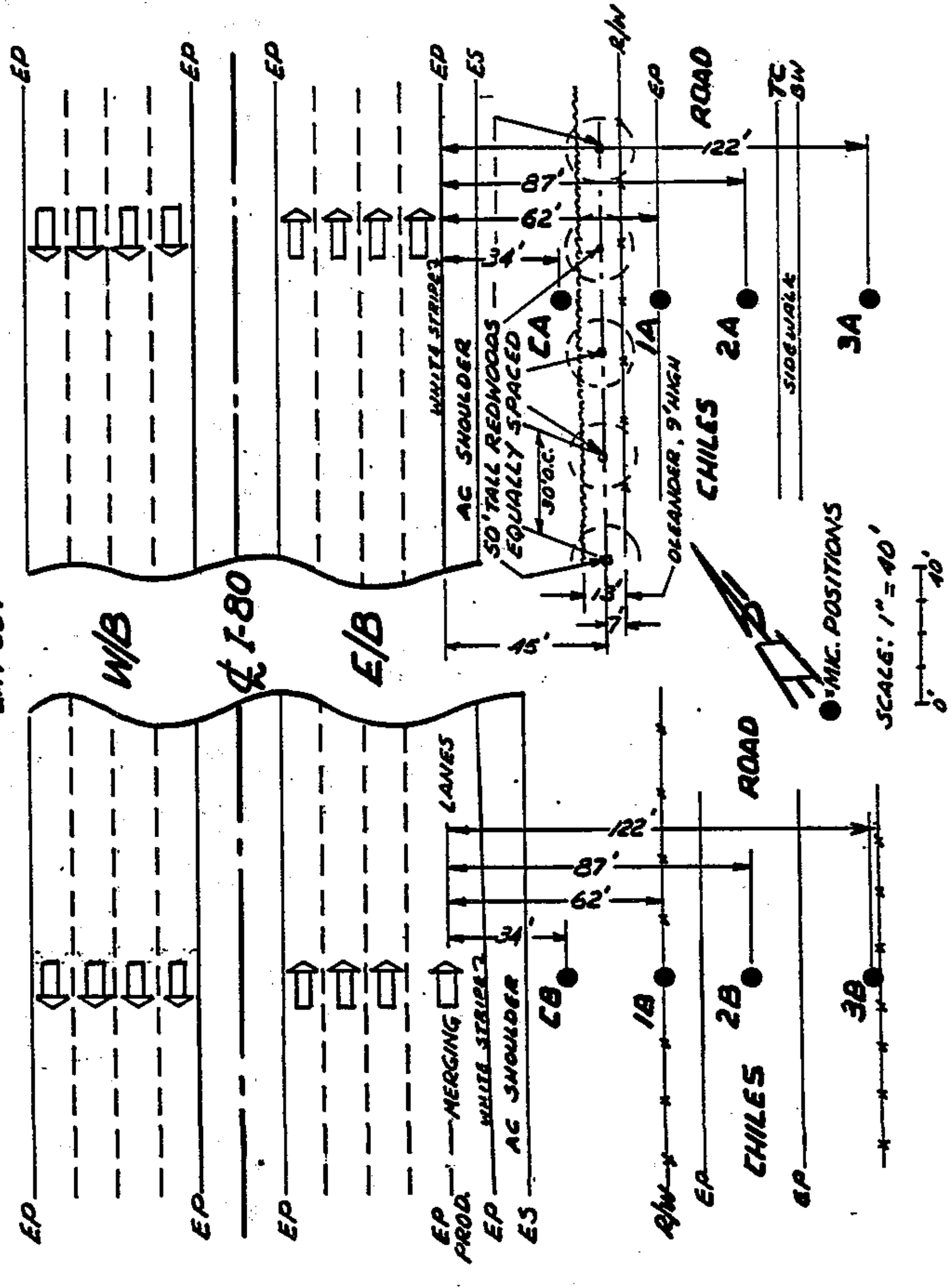


FIGURE A-3 VEGETATION BARRIER SITE V-1
CROSS SECTION

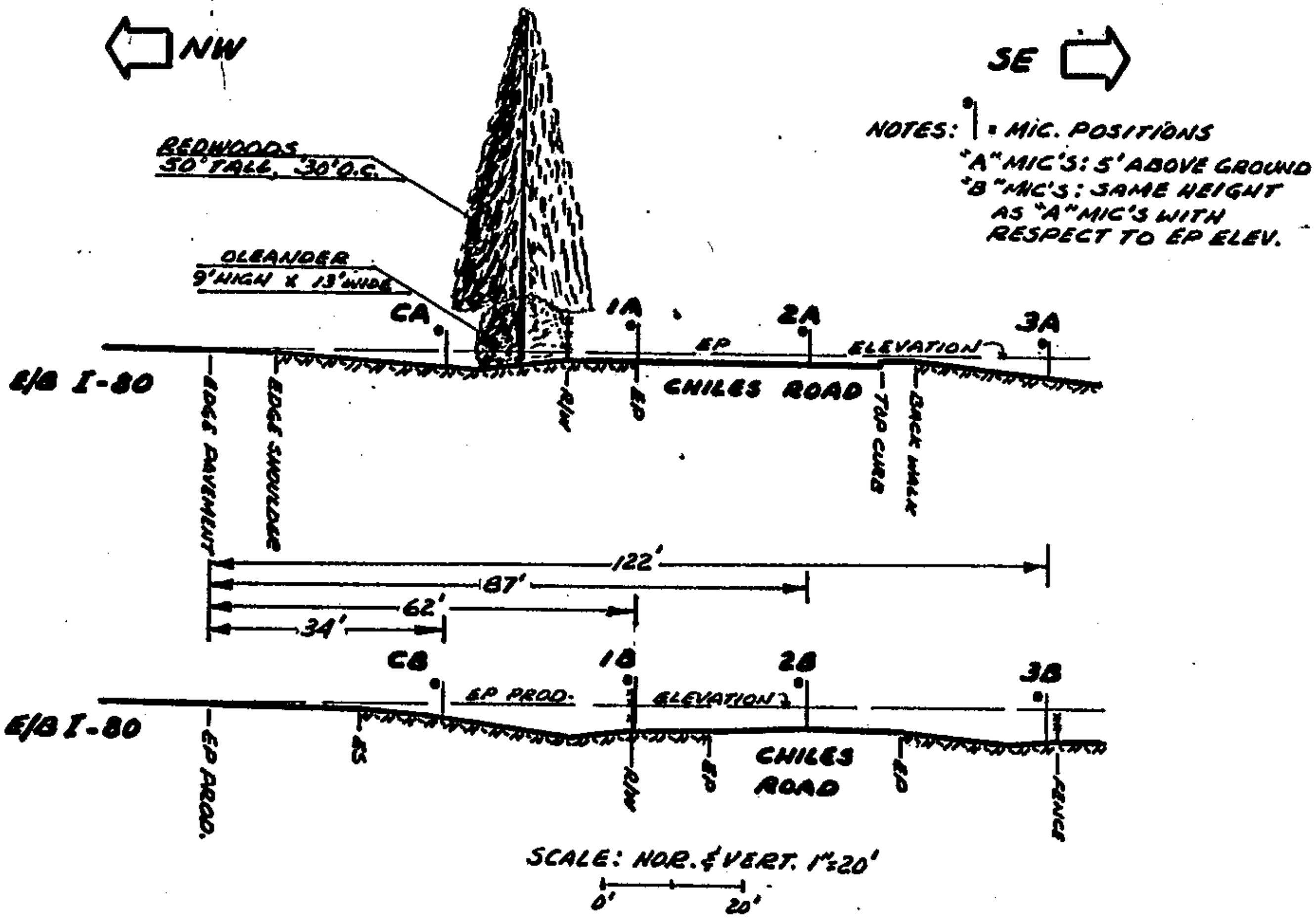
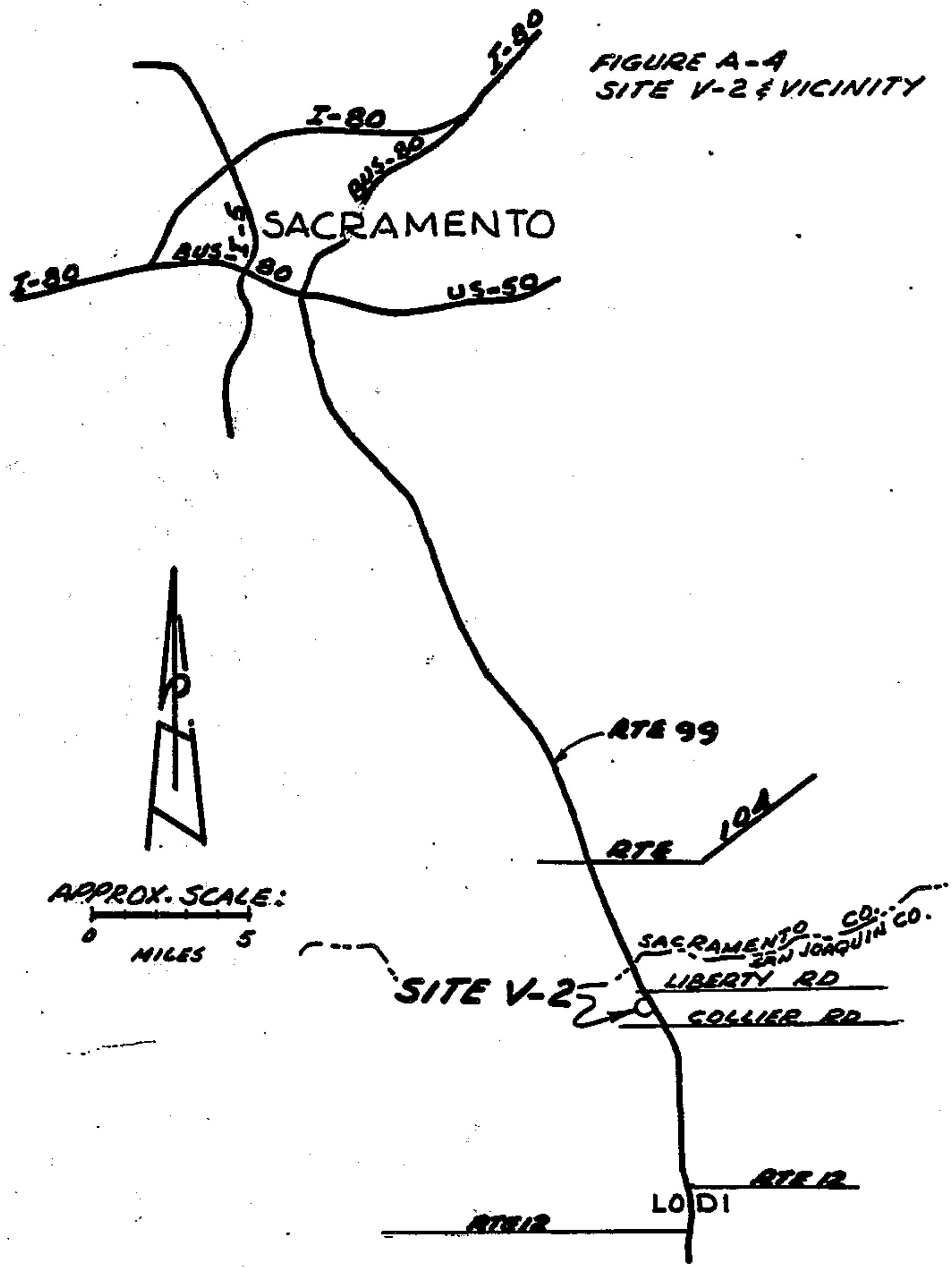


FIGURE A-4
SITE V-2 & VICINITY



## FIGURE A-5 VEGETATIVE BARRIER SITE V-2 LAYOUT

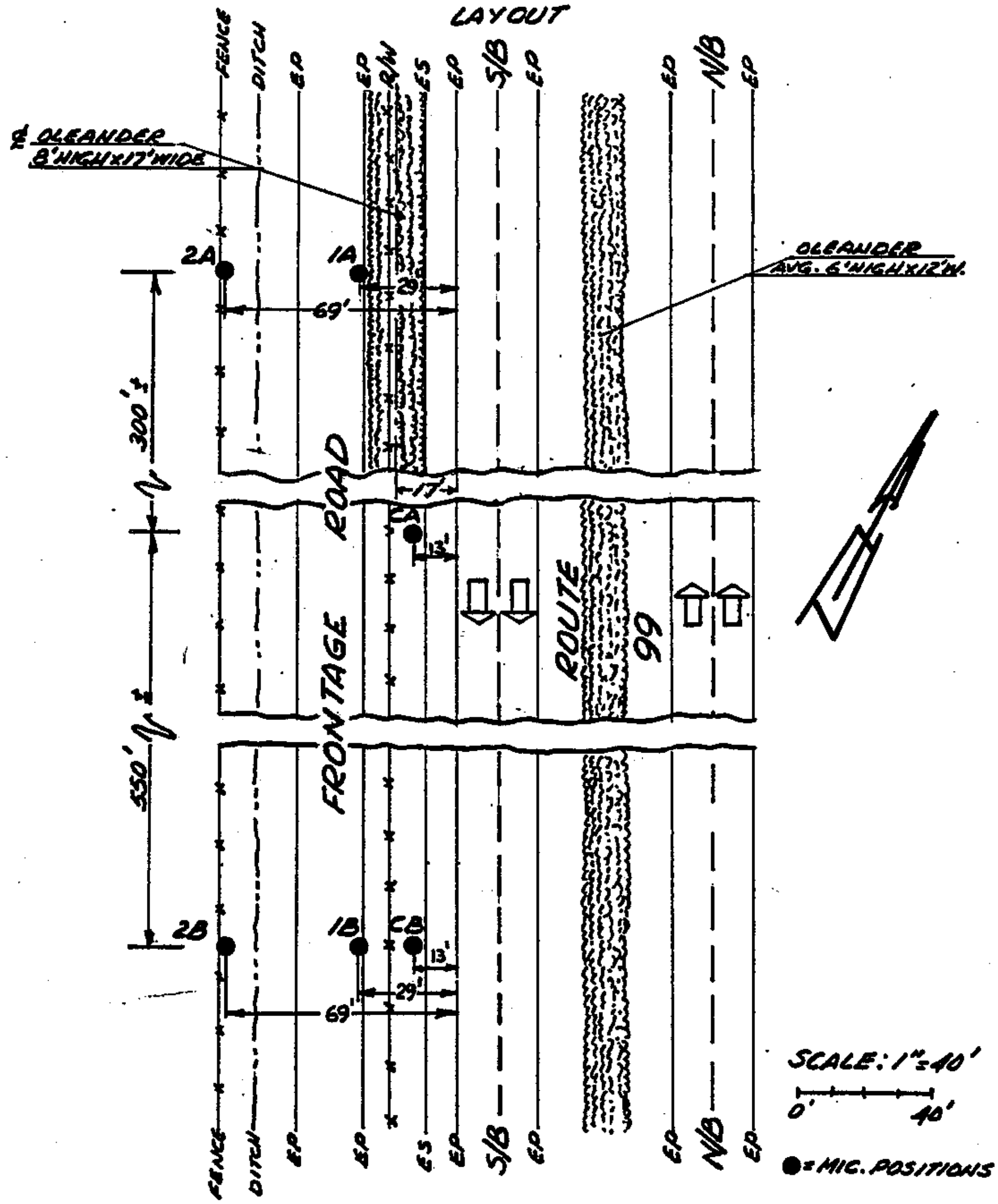


FIGURE A-6-VEGETATIVE BARRIER SITE V-2
CROSS SECTION

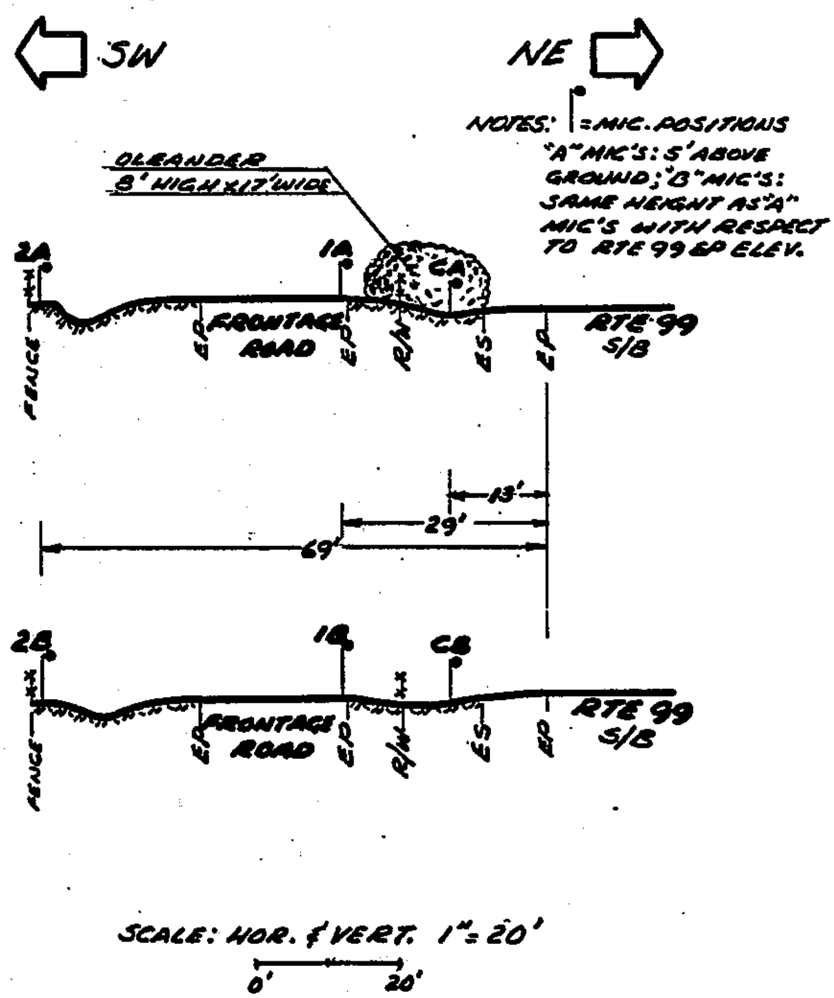


FIGURE A-7-SITE V-3 & VICINITY

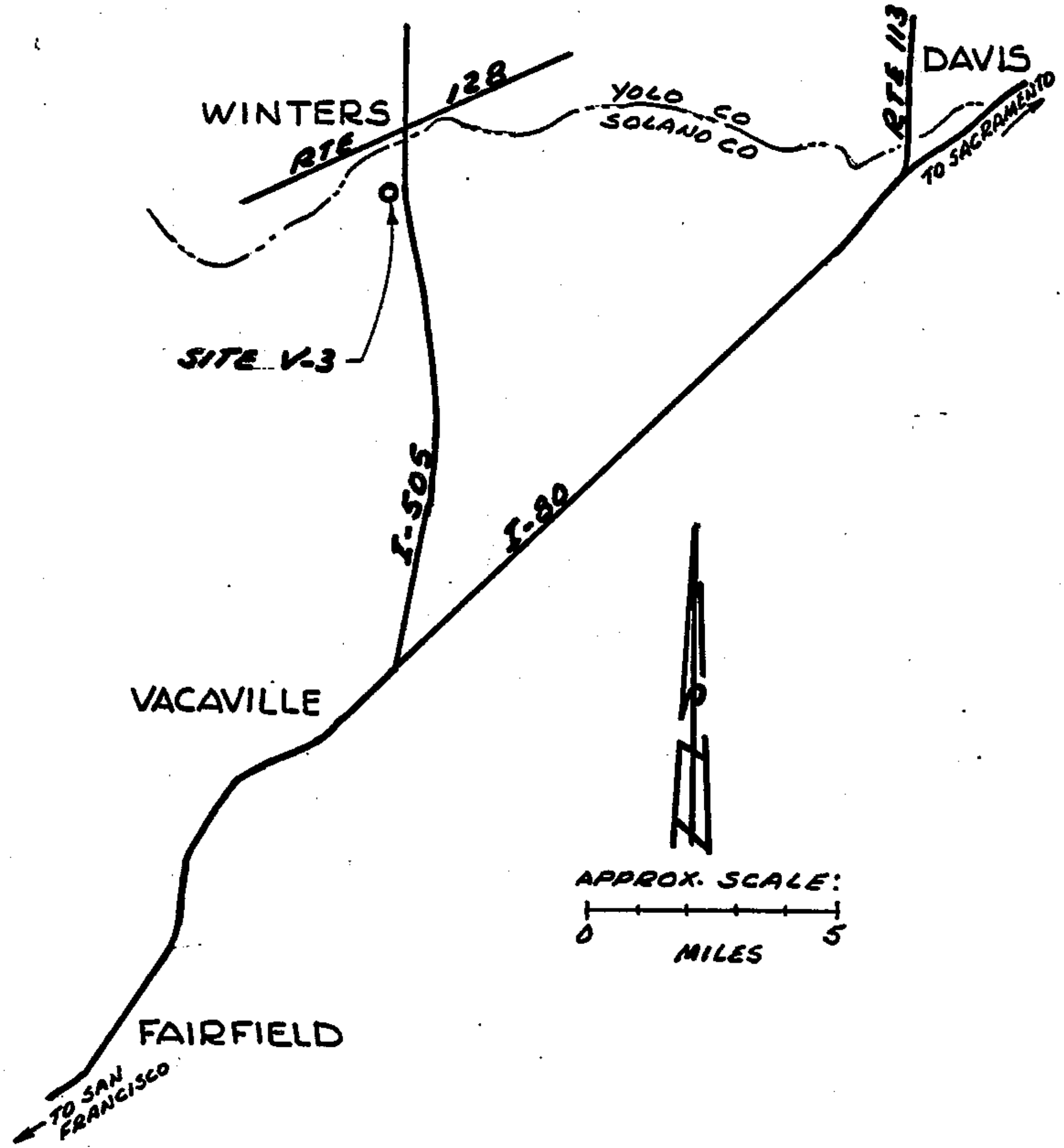


FIGURE A-8 - VEGETATIVE BARRIER SITE V-3
LAYOUT

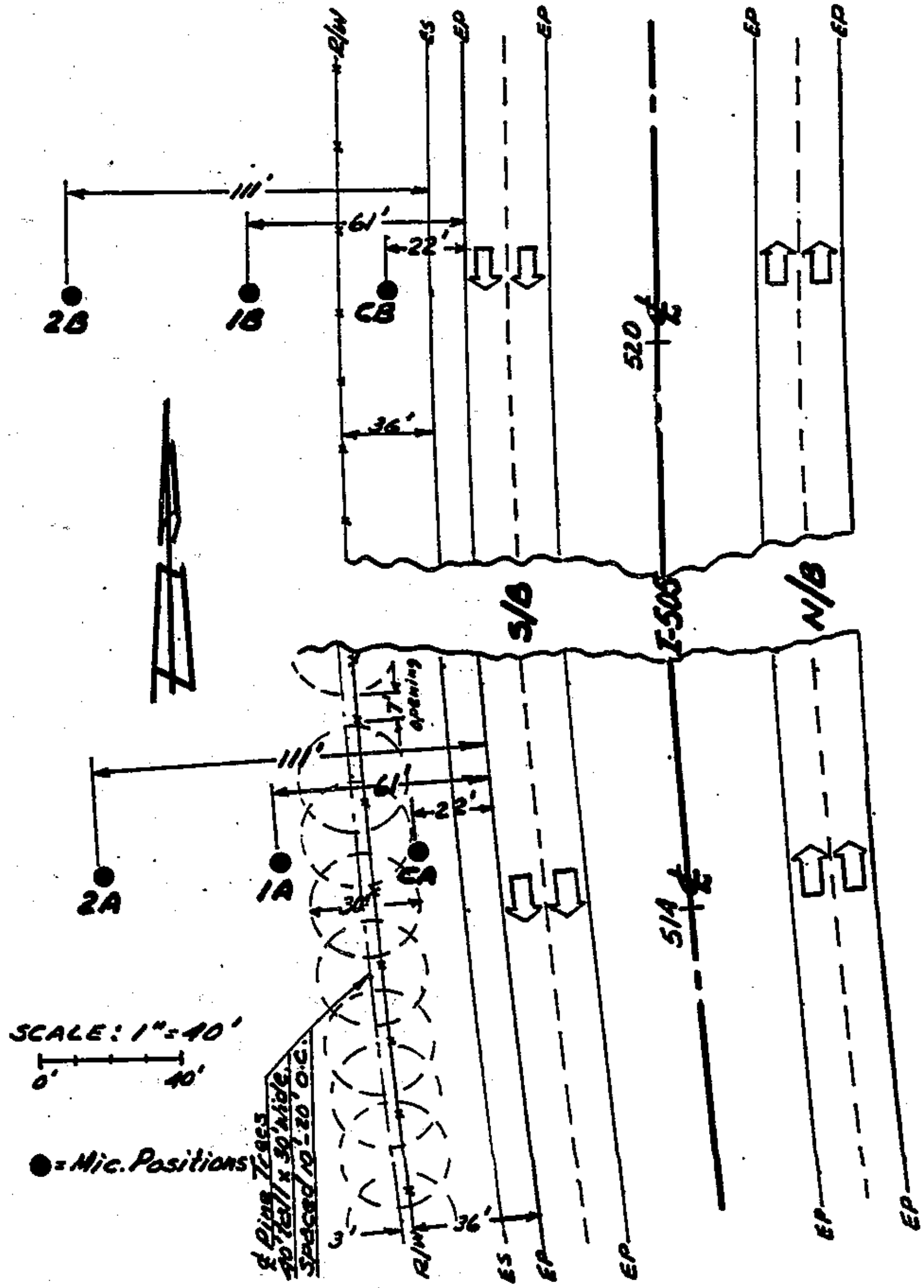
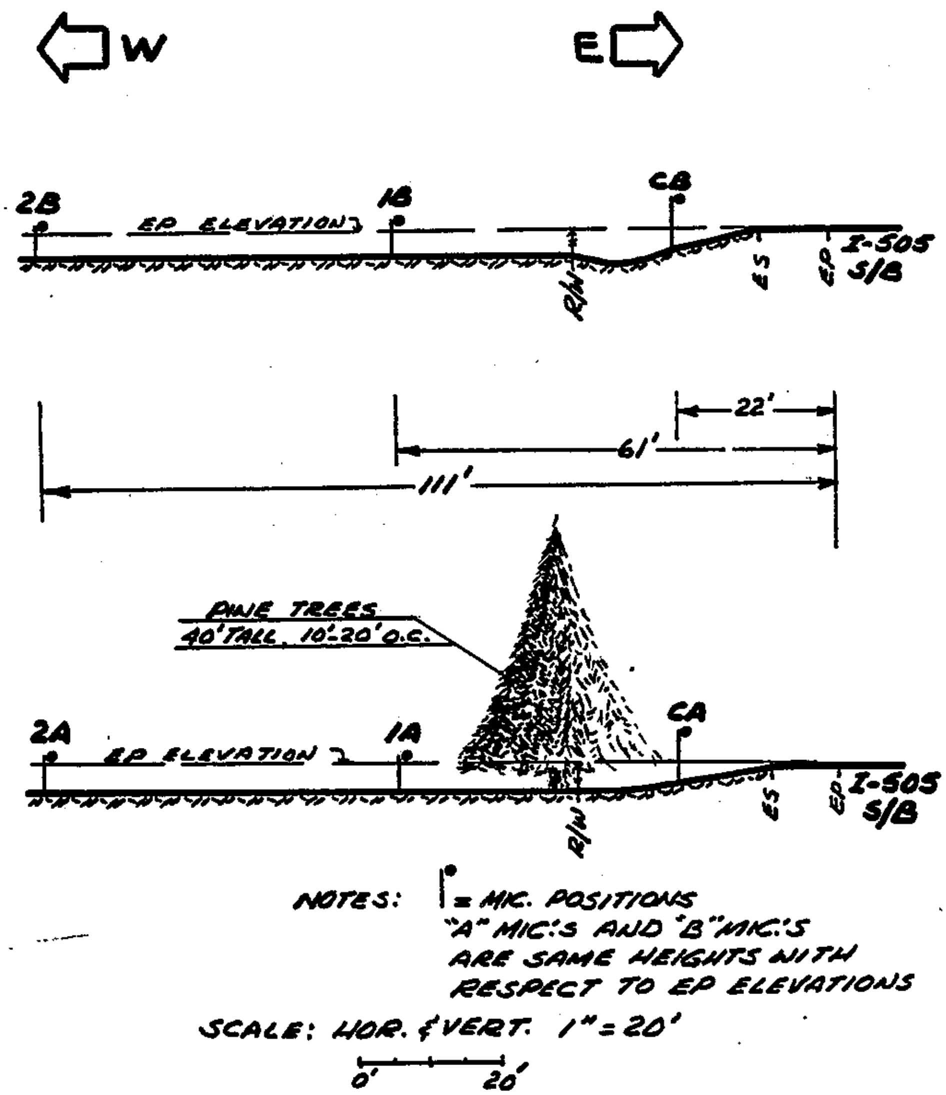


FIGURE A-9-VEGETATIVE BARRIER SITE V-3
CROSS SECTION

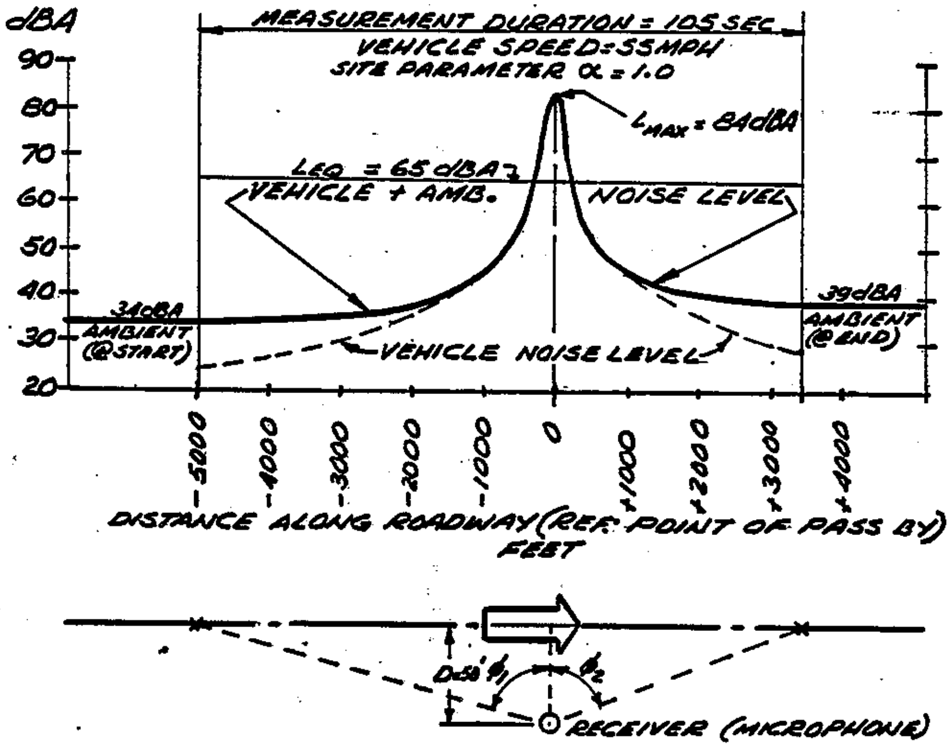


APPENDIX B

GROUND ATTENUATION RATES:

Research Methodology
(See Text)

FIGURE: B-1-NOISE LEVEL PREDICTIONS FOR A TYPICAL HEAVY TRUCK PASS-BY AT 50 FEET




**FHWA MODEL (2): FOR A HEAVY TRUCK: (See Above)**

$L_{eq}(h)_{HT}$ @ RECEIVER = HOURLY EQUIVALENT SOUND LEVEL =

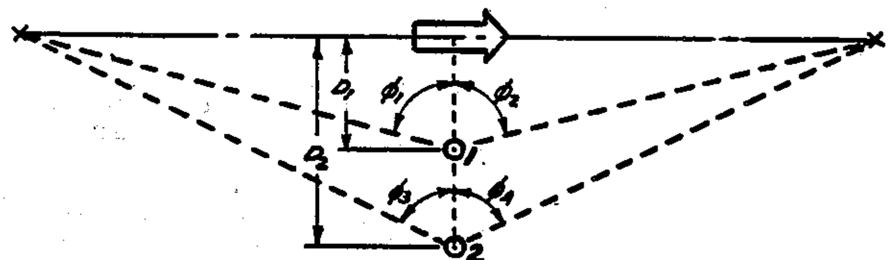
$$= (\bar{L}_0)_{E_{HT}} + 10\log\left(\frac{N_{HT}\pi D_0}{S_{HT}T}\right) + 10\log\left(\frac{D_0}{D}\right)^{1+\alpha} + 10\log\left(\frac{\psi_\alpha(\phi_1,\phi_2)}{\pi}\right)$$

$L_{eq}(h)_{HT} = 49.2$ dBA (USING CALVENO LEVELS (3))

$L_{eq}(105\text{ sec})_{HT}$ = EQUIV. SOUND LEVEL FOR MEAS. DURATION:

$$= L_{eq}(h)_{HT} + 10\log\left(\frac{3600\text{ sec}}{105\text{ sec}}\right) = L_{eq}(h)_{HT} + 15.4 = 64.6\text{ dBA}.$$

FIGURE: B-2- PROCEDURE FOR NORMALIZING MEASURED SINGLE VEHICLE PASS-BY NOISE LEVEL DIFFERENCES BETWEEN TWO RECEIVERS FROM FINITE TO INFINITE ROADWAYS.




FHWA MODEL (2): DIFFERENCE IN NOISE LEVELS @ 1 & 2:

$$L_{eq}(h)_i @1 - L_{eq}(h)_i @2 =$$

$$(\bar{L}_o)_{E_i} + 10\log\left(\frac{N_i \pi D_0}{S_i T}\right) + 10\log\left(\frac{D_0}{D_1}\right)^{1+\alpha} + 10\log\left(\frac{\psi_\alpha(\phi_1,\phi_2)}{\pi}\right)$$

$$-\left[(\bar{L}_o)_{E_i} + 10\log\left(\frac{N_i \pi D_0}{S_i T}\right) + 10\log\left(\frac{D_0}{D_2}\right)^{1+\alpha} + 10\log\left(\frac{\psi_\alpha(\phi_3,\phi_4)}{\pi}\right)\right] =$$

$$= 10\log\left(\frac{D_0}{D_1}\right)^{1+\alpha} - 10\log\left(\frac{D_0}{D_2}\right)^{1+\alpha} +$$

$$+ 10\log\left(\frac{\psi_\alpha(\phi_1,\phi_2)}{\pi}\right) - 10\log\left(\frac{\psi_\alpha(\phi_3,\phi_4)}{\pi}\right)$$

Let $L_{eq}(h)_i @1 - L_{eq}(h)_i @2 = \Delta dBA_{1,2}$

Let $10\log\left(\frac{\psi_\alpha(\phi_1,\phi_2)}{\pi}\right) = SA_1$ (segment adjustment @1)

Let $10\log\left(\frac{\psi_\alpha(\phi_3,\phi_4)}{\pi}\right) = SA_2$ (segment adjustment @2)

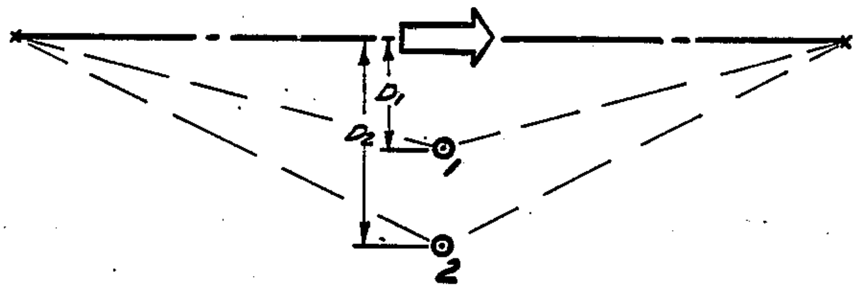
Then: $\Delta dBA_{1,2} = 10\log\left(\frac{D_0}{D_1}\right)^{1+\alpha} - 10\log\left(\frac{D_0}{D_2}\right)^{1+\alpha} + SA_1 - SA_2$

$$\Delta dBA_{1,2} = 10\log\left(\frac{D_2}{D_1}\right)^{1+\alpha} + SA_1 - SA_2 \qquad [Eq.1]$$

To normalize measured $\Delta dBA_{1,2}$(FIN) for finite roadway to $\Delta dBA_{1,2}$(INF) for infinite roadway, segment adjustments must be taken out, i.e. the process must be reversed:

$$\boxed{\Delta dBA_{1,2}(INF) = \Delta dBA_{1,2}(FIN) + SA_2 - SA_1} \qquad [Eq.2]$$

FIGURE: B-3 CALCULATION OF SITE PARAMETER, $\alpha$




FOR PASSBY $L_{EQ}$:

$$\Delta dBA_{1,2}(INF) = 10 Log\left(\frac{D_2}{D_1}\right)^{1+\alpha} \qquad (2)$$

$$0.1\ \Delta dBA_{1,2}(INF) = (1+\alpha)\log\left(\frac{D_2}{D_1}\right)$$

$$1+\alpha = 0.1\ \Delta dBA_{1,2}(INF)/\log\left(\frac{D_2}{D_1}\right)$$

$$\boxed{\alpha = \left[0.1(\Delta dBA_{1,2}(INF))/\log\left(\frac{D_2}{D_1}\right)\right]-1} \qquad (Eq. 3)$$

FOR PASSBY $L_{MAX}$:

$$\Delta dBA_{1,2} = 10\log\left(\frac{D_2}{D_1}\right)^{2+\alpha} \qquad (2)$$

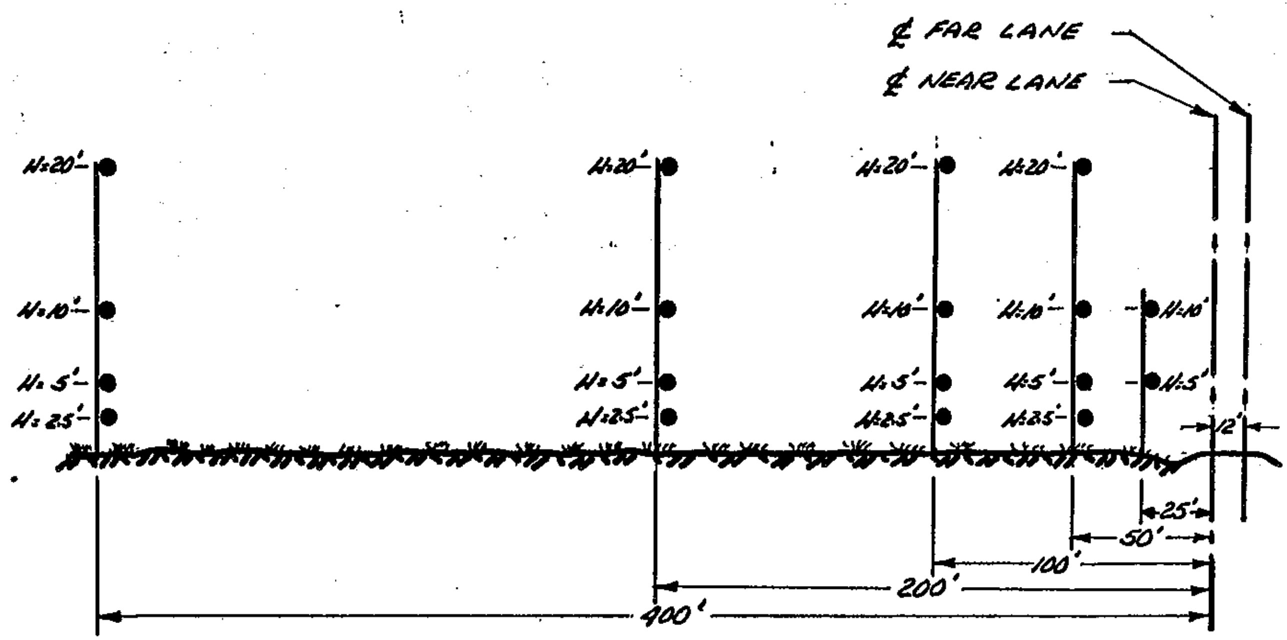
$$\boxed{\alpha = \left[0.1(\Delta dBA_{1,2})/\log\left(\frac{D_2}{D_1}\right)\right]-2} \qquad (Eq. 4)$$

where: $\Delta dBA_{1,2}(INF)$ is defined by Eq. 2, Fig.

$\Delta dBA_{1,2} = L_{max} @ 1 - L_{max} @ 2$

$D_1$ and $D_2$ are distances from ℄ travel to receivers 1 & 2 respectively.

FIGURE: B-4-TYPICAL MIC POSITIONS FOR
GROUND ATTENUATION RATE MEASUREMENTS
(SINGLE VEHICLE PASS ON 2-LANE RURAL HIGHWAY)



# APPENDIX C

## GROUND ATTENUATION RATES:

Calculated Alphas for Sites G-1, G-2, G-3, and G-4
(See Text)

LISTING OF G1 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G1-1 | A | 2.0 | 1.3 | 0.0 |
| G1-2 | A | 1.5 | 1.3 | 0.0 |
| G1-3 | A | 2.1 | 1.6 | 0.0 |
| G1-4 | A | 2.0 | 1.8 | 0.0 |
| G1-5 | A | 2.4 | 2.0 | 0.0 |
| G1-6 | A | 2.3 | 1.9 | 0.0 |
| G1-7 | A | 1.8 | 1.2 | 0.0 |
| G1-9 | A | 1.7 | 1.7 | -1.2 |
| G1-10 | A | 1.9 | 1.9 | 0.0 |
| G1-11 | A | 1.6 | 2.4 | 0.0 |
| G1-13 | A | 1.6 | 1.8 | 0.0 |
| G1-14 | A | 1.8 | 1.4 | 0.0 |
| G1-15 | A | 1.6 | 1.9 | 0.0 |
| G1-17 | A | 1.5 | 1.2 | 0.0 |
| G1-20 | A | 1.5 | 1.0 | 0.0 |
| G1-22 | A | 2.0 | 1.3 | 1.2 |
| G1-23 | A | 2.0 | 1.6 | 0.0 |
| G1-24 | A | 1.9 | 1.3 | 0.0 |
| G1-25 | A | 2.4 | 1.9 | 0.0 |
| G1-26 | A | 2.1 | 1.4 | 0.0 |
| G1-27 | A | 1.9 | 1.6 | 0.0 |
| G1-28 | A | 1.5 | 1.1 | 0.0 |
| G1-29 | A | 1.7 | 1.3 | 0.0 |
| G1-30 | A | 1.9 | 1.4 | 0.0 |
| G1-31 | A | 2.5 | 2.1 | 0.0 |
| G1-32 | A | 2.3 | 1.8 | 0.0 |
| G1-33 | A | 2.4 | 1.4 | 0.0 |
| G1-35 | A | 2.1 | 1.6 | 0.0 |
| G1-36 | A | 2.4 | 1.6 | 0.0 |
| G1-37 | A | 2.5 | 2.1 | 0.0 |
| G1-38 | A | 2.4 | 2.0 | 0.0 |
| G1-39 | A | 2.1 | 1.1 | 0.0 |
| G1-40 | A | 2.3 | 1.8 | 1.1 |
| G1-43 | A | 2.1 | 1.8 | 3.0 |
| G1-44 | A | 2.2 | 1.4 | 0.0 |
| G1-45 | A | 2.4 | 1.6 | 0.0 |
| G1-46 | A | 2.1 | 1.8 | 0.0 |
| G1-53 | A | 2.5 | 1.9 | -1.0 |
| G1-54 | A | 2.1 | 1.4 | -1.0 |
| G1-55 | A | 2.0 | 1.6 | -1.1 |
| G1-57 | A | 1.1 | 1.6 | 0.2 |
| G1-59 | A | 1.3 | 1.7 | 0.0 |
| G1-68 | A | 2.0 | 1.2 | 0.0 |
| G1-69 | A | 2.9 | 2.0 | -1.0 |
| G1-70 | A | 2.1 | 1.7 | -3.0 |
| G1-73 | A | 2.3 | 1.5 | -1.0 |
| G1-76 | A | 2.5 | 2.3 | -3.0 |
| G1-85 | A | 2.3 | 2.2 | -1.2 |
| G1-86 | A | 2.5 | 2.1 | -1.2 |
| G1-88 | A | 3.0 | 2.6 | -3.0 |
| G1-91 | A | 2.5 | 1.8 | -3.5 |
| G1-92 | A | 2.6 | 2.1 | -3.5 |
| G1-98 | A | 2.5 | 2.5 | -3.4 |
| G1-99 | A | 1.9 | 1.4 | -1.0 |
| G1-102 | A | 2.6 | 2.3 | 0.0 |

LISTING OF G1 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G1-105 | A | 2.5 | 2.5 | 0.0 |
| G1-108 | A | 1.9 | 1.4 | 0.0 |
| G1-110 | A | 2.0 | 1.3 | 1.2 |
| G1-116 | A | 2.5 | 2.1 | 0.0 |
| G1-122 | A | 2.5 | 2.1 | 0.0 |
| G1-123 | A | 1.8 | 1.4 | 1.2 |
| AVERAGE | | 2.1 | 1.7 | |

LISTING OF G1 MEDIUM TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G1-18 | MT | 1.7 | 1.2 | 0.0 |
| G1-48 | MT | 1.4 | 1.2 | 0.0 |
| G1-52 | MT | 2.1 | 2.0 | -1.2 |
| G1-117 | MT | 2.4 | 2.1 | -3.0 |
| AVERAGE | | 1.9 | 1.6 | |

LISTING OF G1 HEAVY TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G1-8 | HT | 1.6 | 1.2 | 0.0 |
| G1-12 | HT | 1.3 | 0.8 | 1.2 |
| G1-21 | HT | 1.6 | 1.2 | 0.0 |
| G1-47 | HT | 2.1 | 1.5 | 0.0 |
| G1-49 | HT | 1.8 | 1.1 | 0.0 |
| G1-51 | HT | 1.7 | 0.8 | -1.2 |
| G1-62 | HT | 2.4 | 1.1 | -1.0 |
| G1-64 | HT | 1.5 | 0.9 | 0.0 |
| G1-65 | HT | 1.3 | 0.7 | 0.6 |
| G1-66 | HT | 1.3 | 0.9 | 0.0 |
| G1-67 | HT | 1.7 | 1.2 | -1.1 |
| G1-71 | HT | 1.9 | 1.0 | -1.0 |
| G1-74 | HT | 2.0 | 1.0 | -1.0 |
| G1-77 | HT | 1.7 | 0.5 | -1.0 |
| G1-78 | HT | 2.5 | 1.2 | -1.2 |
| G1-79 | HT | 1.7 | 0.7 | -0.4 |
| G1-80 | HT | 2.3 | 1.6 | -1.2 |
| G1-81 | HT | 2.4 | 1.8 | -1.0 |
| G1-82 | HT | 2.1 | 0.8 | -3.5 |
| G1-83 | HT | 2.8 | 2.0 | -1.0 |
| G1-84 | HT | 1.3 | 0.3 | -1.2 |
| G1-87 | HT | 2.2 | 1.4 | -1.2 |
| G1-89 | HT | 2.0 | 0.9 | -1.0 |
| G1-93 | HT | 1.5 | 1.1 | -0.7 |
| G1-95 | HT | 1.9 | 1.1 | 0.0 |
| G1-96 | HT | 1.8 | 1.3 | 0.0 |
| G1-100 | HT | 1.8 | 1.1 | -1.0 |
| G1-101 | HT | 2.3 | 0.8 | 0.0 |
| G1-103 | HT | 2.1 | 1.4 | 0.0 |
| G1-104 | HT | 1.8 | 1.2 | 0.0 |
| G1-106 | HT | 2.2 | 0.9 | -1.0 |
| G1-107 | HT | 2.2 | 1.6 | -3.0 |
| G1-112 | HT | 2.2 | 1.6 | -3.5 |
| G1-115 | HT | 1.7 | 1.0 | -1.0 |
| G1-119 | HT | 2.2 | 2.1 | 0.0 |
| G1-120 | HT | 1.7 | 0.5 | 0.0 |
| G1-124 | HT | 2.0 | 1.5 | 0.0 |
| AVERAGE | | 1.9 | 1.1 | |

LISTING OF G2 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G2-1 | A | 2.4 | 1.8 | 0.0 |
| G2-2 | A | 2.0 | 1.6 | 0.0 |
| G2-3 | A | 1.9 | 1.2 | 0.0 |
| G2-4 | A | 1.8 | 1.4 | -3.0 |
| G2-5 | A | 2.6 | 2.0 | -5.0 |
| G2-8 | A | 1.5 | 1.4 | 0.0 |
| G2-9 | A | 1.9 | 1.9 | 0.0 |
| G2-10 | A | 1.6 | 1.5 | 0.0 |
| G2-11 | A | 1.8 | 1.4 | 0.0 |
| G2-13 | A | 2.0 | 1.6 | 0.0 |
| G2-15 | A | 2.1 | 1.8 | 0.0 |
| G2-16 | A | 2.3 | 1.8 | 0.0 |
| G2-17 | A | 1.8 | 1.2 | 0.0 |
| G2-18 | A | 2.3 | 1.8 | 0.0 |
| G2-19 | A | 1.5 | 1.2 | 0.0 |
| G2-21 | A | 1.7 | 1.4 | 0.0 |
| G2-22 | A | 1.8 | 1.5 | 0.0 |
| G2-23 | A | 1.9 | 1.8 | 0.0 |
| G2-25 | A | 1.4 | 1.2 | 0.0 |
| G2-27 | A | 2.1 | 1.6 | 0.0 |
| G2-28 | A | 2.0 | 1.6 | 0.0 |
| G2-29 | A | 1.8 | 1.4 | 0.0 |
| G2-30 | A | 1.9 | 1.5 | 0.0 |
| G2-31 | A | 1.9 | 1.4 | 0.0 |
| G2-33 | A | 1.8 | 1.4 | 0.0 |
| G2-34 | A | 1.9 | 1.6 | 0.0 |
| G2-35 | A | 2.0 | 1.5 | 0.0 |
| G2-36 | A | 1.8 | 1.5 | 0.0 |
| G2-38 | A | 2.0 | 1.8 | 1.7 |
| G2-39 | A | 2.1 | 1.6 | 0.0 |
| G2-41 | A | 2.0 | 1.6 | 0.0 |
| G2-42 | A | 1.9 | 1.3 | 1.0 |
| G2-44 | A | 2.1 | 1.4 | 1.2 |
| G2-46 | A | 2.0 | 1.3 | 0.0 |
| G2-47 | A | 2.1 | 1.7 | 0.0 |
| G2-48 | A | 1.8 | 1.4 | 2.9 |
| G2-49 | A | 2.1 | 1.6 | 0.0 |
| G2-52 | A | 1.3 | 0.7 | 0.0 |
| G2-53 | A | 1.5 | 1.3 | 0.0 |
| G2-54 | A | 2.2 | 1.6 | 1.2 |
| G2-55 | A | 2.0 | 1.4 | 0.0 |
| G2-56 | A | 1.5 | 1.1 | -1.0 |
| G2-57 | A | 2.6 | 1.8 | -1.0 |
| G2-58 | A | 2.6 | 2.1 | -0.6 |
| G2-59 | A | 2.7 | 2.2 | -3.5 |
| G2-60 | A | 2.1 | 1.6 | 0.0 |
| G2-61 | A | 2.2 | 1.5 | 0.0 |
| G2-62 | A | 2.3 | 1.7 | 0.0 |
| G2-63 | A | 2.9 | 2.5 | 0.0 |
| G2-65 | A | 1.6 | 1.3 | 0.0 |
| G2-66 | A | 1.8 | 1.4 | 0.6 |
| G2-67 | A | 2.3 | 1.8 | 0.0 |
| G2-69 | A | 2.7 | 2.2 | -1.2 |
| G2-70 | A | 1.6 | 1.3 | 0.0 |
| G2-71 | A | 2.4 | 1.9 | 0.0 |

LISTING OF G2 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G2-72 | A | 2.1 | 1.6 | 0.0 |
| G2-73 | A | 2.4 | 1.9 | -2.2 |
| G2-75 | A | 2.1 | 1.8 | -1.7 |
| G2-76 | A | 2.0 | 1.5 | 0.0 |
| G2-77 | A | 2.2 | 1.7 | 0.0 |
| G2-78 | A | 2.2 | 1.8 | 0.0 |
| G2-79 | A | 2.5 | 2.2 | 0.0 |
| G2-81 | A | 2.2 | 1.9 | 0.0 |
| G2-84 | A | 2.2 | 1.6 | 0.0 |
| G2-85 | A | 1.8 | 1.3 | 0.6 |
| G2-86 | A | 2.6 | 2.3 | 0.0 |
| G2-87 | A | 2.1 | 1.5 | 0.0 |
| G2-88 | A | 2.1 | 1.5 | 0.6 |
| G2-89 | A | 2.5 | 2.4 | 0.0 |
| G2-90 | A | 2.4 | 1.7 | 0.0 |
| G2-91 | A | 2.6 | 1.9 | 0.0 |
| G2-93 | A | 2.2 | 1.6 | 1.7 |
| G2-94 | A | 2.1 | 1.5 | 0.6 |
| G2-96 | A | 2.5 | 2.3 | 1.2 |
| G2-97 | A | 2.5 | 2.1 | 2.0 |
| G2-98 | A | 1.8 | 1.4 | 0.0 |
| G2-99 | A | 2.4 | 1.8 | 0.0 |
| G2-100 | A | 2.5 | 2.2 | 2.4 |
| G2-101 | A | 1.7 | 1.3 | 3.5 |
| G2-102 | A | 2.4 | 1.8 | 0.0 |
| G2-103 | A | 2.1 | 1.9 | 0.0 |
| G2-104 | A | 2.7 | 2.0 | 0.0 |
| G2-106 | A | 1.6 | 0.9 | 0.0 |
| G2-107 | A | 2.2 | 1.8 | 2.9 |
| G2-108 | A | 1.9 | 1.7 | 0.0 |
| G2-110 | A | 2.1 | 1.5 | 1.7 |
| G2-111 | A | 2.1 | 1.5 | 1.2 |
| G2-112 | A | 2.4 | 1.9 | 0.0 |
| G2-113 | A | 2.1 | 1.6 | 0.0 |
| G2-115 | A | 2.2 | 1.7 | 0.0 |
| G2-117 | A | 2.6 | 2.3 | -2.4 |
| G2-118 | A | 2.6 | 1.9 | -2.9 |
| G2-120 | A | 2.0 | 1.6 | 0.0 |
| G2-121 | A | 2.1 | 1.7 | 0.0 |
| G2-123 | A | 2.4 | 2.2 | 1.7 |
| G2-127 | A | 2.8 | 2.7 | -1.7 |
| G2-128 | A | 2.9 | 2.7 | 0.0 |
| G2-129 | A | 2.5 | 2.0 | 0.0 |
| G2-130 | A | 2.3 | 1.5 | 0.0 |
| G2-134 | A | 1.5 | 1.0 | 0.0 |
| G2-135 | A | 2.0 | 1.6 | 4.0 |
| G2-136 | A | 1.7 | 1.9 | 0.0 |
| G2-137 | A | 2.6 | 2.2 | 0.0 |
| G2-138 | A | 2.3 | 1.7 | 0.0 |
| G2-140 | A | 1.6 | 1.2 | 4.0 |
| G2-141 | A | 1.6 | 1.3 | 4.1 |
| G2-143 | A | 2.3 | 1.7 | 0.0 |
| G2-144 | A | 1.8 | 1.4 | 0.0 |
| G2-145 | A | 2.2 | 1.5 | 0.0 |
| G2-146 | A | 2.1 | 1.6 | 2.1 |
| G2-147 | A | 1.8 | 1.7 | 4.0 |

LISTING OF G2 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G2-148 | A | 2.4 | 2.2 | 5.2 |
| G2-149 | A | 1.4 | 1.0 | 5.2 |
| G2-151 | A | 2.3 | 1.8 | 0.0 |
| G2-152 | A | 2.1 | 2.0 | 0.0 |
| G2-155 | A | 2.0 | 1.7 | 0.0 |
| G2-156 | A | 1.9 | 1.6 | 0.0 |
| G2-157 | A | 2.7 | 2.3 | 0.0 |
| G2-158 | A | 2.7 | 2.4 | 0.0 |
| G2-159 | A | 2.9 | 2.4 | -1.7 |
| G2-160 | A | 2.1 | 1.6 | 0.0 |
| G2-161 | A | 1.2 | 0.9 | 0.0 |
| G2-162 | A | 1.8 | 1.3 | 2.0 |
| G2-163 | A | 2.1 | 1.7 | 0.6 |
| G2-165 | A | 2.1 | 2.0 | 0.0 |
| G2-166 | A | 1.3 | 1.1 | 5.0 |
| AVERAGE | | 2.1 | 1.7 | |

LISTING OF G2 MEDIUM TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G2-50 | MT | 2.0 | 1.6 | 0.0 |
| G2-105 | MT | 2.1 | 1.5 | 0.0 |
| G2-164 | MT | 1.9 | 1.8 | 0.0 |
| AVERAGE | | 2.0 | 1.6 | |

LISTING OF G2 HEAVY TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G2-12 | HT | 1.0 | 1.0 | 0.0 |
| G2-14 | HT | 1.4 | 0.8 | 0.0 |
| G2-24 | HT | 0.9 | 0.3 | 0.0 |
| G2-26 | HT | 1.0 | 0.8 | -1.7 |
| G2-43 | HT | 1.6 | 1.0 | 1.2 |
| G2-51 | HT | 1.2 | 0.8 | 0.0 |
| G2-64 | HT | 1.4 | 0.9 | 0.0 |
| G2-82 | HT | 1.4 | 1.0 | 0.0 |
| G2-95 | HT | 1.4 | 0.8 | 1.7 |
| G2-114 | HT | 1.9 | 1.4 | 0.0 |
| G2-116 | HT | 2.2 | 1.6 | 0.0 |
| G2-125 | HT | 1.4 | 1.0 | 0.0 |
| G2-126 | HT | 2.0 | 1.6 | -1.7 |
| G2-132 | HT | 0.8 | 0.5 | 4.0 |
| G2-133 | HT | 1.9 | 0.9 | 4.0 |
| G2-154 | HT | 1.6 | 0.9 | 0.0 |
| G2-167 | HT | 1.5 | 1.1 | 0.0 |
| | | | | |
| AVERAGE | | 1.4 | 1.0 | |

LISTING OF G3 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G3-1 | A | 1.8 | 1.5 | -1.2 |
| G3-2 | A | 1.7 | 1.3 | -1.2 |
| G3-9 | A | 2.2 | 1.8 | -1.0 |
| G3-13 | A | 2.1 | 1.8 | -5.0 |
| G3-15 | A | 2.1 | 1.8 | -5.0 |
| G3-18 | A | 1.8 | 1.4 | -3.2 |
| G3-20 | A | 1.7 | 1.8 | -3.0 |
| G3-21 | A | 2.0 | 1.8 | -3.0 |
| G3-22 | A | 2.3 | 2.2 | -3.0 |
| G3-25 | A | 1.7 | 1.4 | -3.0 |
| G3-26 | A | 1.6 | 1.2 | -0.4 |
| G3-30 | A | 1.7 | 1.5 | -1.0 |
| G3-35 | A | 1.5 | 1.0 | 0.2 |
| G3-38 | A | 1.9 | 1.3 | 0.2 |
| G3-39 | A | 1.6 | 1.1 | 0.9 |
| G3-43 | A | 1.6 | 1.2 | 0.8 |
| G3-48 | A | 1.5 | 1.2 | 0.0 |
| G3-49 | A | 1.4 | 1.0 | 0.0 |
| G3-50 | A | 1.6 | 1.3 | 0.0 |
| G3-51 | A | 1.5 | 1.3 | 0.6 |
| G3-54 | A | 2.0 | 1.2 | 3.4 |
| AVERAGE | | 1.8 | 1.4 | |

LISTING OF G3 MEDIUM TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G3-23 | MT | 1.3 | 1.0 | -1.2 |
| G3-29 | MT | 1.0 | 0.9 | -1.2 |
| G3-32 | MT | 1.9 | 1.4 | -1.2 |
| G3-33 | MT | 1.2 | 0.8 | -1.0 |
| G3-42 | MT | 1.1 | 0.8 | 0.8 |
| AVERAGE | | 1.3 | 1.0 | |

LISTING OF G3 HEAVY TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G3-3 | HT | 1.1 | 0.9 | -3.5 |
| G3-5 | HT | 1.2 | 0.9 | -1.0 |
| G3-7 | HT | 1.2 | 0.5 | -3.0 |
| G3-10 | HT | 1.1 | 0.2 | -1.1 |
| G3-14 | HT | 1.3 | 0.9 | -3.0 |
| G3-16 | HT | 1.4 | 1.2 | -5.0 |
| G3-24 | HT | 1.2 | 0.9 | -1.2 |
| G3-27 | HT | 0.7 | 0.8 | -1.1 |
| G3-31 | HT | 1.0 | 0.9 | -1.2 |
| G3-36 | HT | 0.9 | 0.7 | 0.2 |
| G3-37 | HT | 0.9 | 0.6 | 0.6 |
| G3-44 | HT | 0.9 | 0.5 | 0.0 |
| G3-45 | HT | 1.0 | 0.4 | 0.0 |
| G3-47 | HT | 0.8 | 0.4 | 0.0 |
| G3-52 | HT | 1.7 | 1.2 | 0.0 |
| G3-53 | HT | 1.0 | 0.6 | 0.6 |
| G3-55 | HT | 0.8 | 0.7 | 0.6 |
| G3-56 | HT | 1.0 | 0.5 | 1.7 |
| AVERAGE | | 1.1 | 0.7 | |

LISTING OF G4 AUTO DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G4-2 | A | 1.6 | 1.3 | -3.5 |
| G4-3 | A | 1.4 | 0.8 | -1.2 |
| G4-5 | A | 1.2 | 0.8 | -1.2 |
| G4-8 | A | 1.3 | 1.0 | -1.2 |
| G4-9 | A | 1.5 | 1.0 | -1.2 |
| G4-11 | A | 1.5 | 1.0 | -3.5 |
| G4-12 | A | 1.1 | 0.9 | -1.2 |
| G4-13 | A | 1.9 | 1.2 | -3.5 |
| G4-14 | A | 0.9 | 0.6 | 1.2 |
| G4-17 | A | 1.0 | 0.5 | -1.2 |
| G4-21 | A | 1.3 | 0.8 | 3.0 |
| G4-23 | A | 0.9 | 0.7 | 0.6 |
| G4-24 | A | 1.3 | 1.0 | 3.5 |
| G4-26 | A | 0.9 | 0.6 | 3.4 |
| G4-27 | A | 1.0 | 0.5 | 3.5 |
| G4-28 | A | 1.1 | 0.7 | 8.1 |
| AVERAGE | | 1.2 | 0.8 | |

LISTING OF G4 MEDIUM TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G4-15 | MT | 0.9 | 0.5 | 3.0 |
| G4-18 | MT | 1.6 | 0.9 | -1.2 |
| G4-20 | MT | 1.0 | 0.5 | 1.7 |
| AVERAGE | | 1.2 | 0.6 | |

LISTING OF G4 HEAVY TRUCK DATA:

| ID_NO | VEH | ALPHA | PKALPHA | CWC |
|---|---|---|---|---|
| G4-6 | HT | 1.0 | 0.6 | -1.2 |
| G4-19 | HT | 0.9 | 0.3 | 3.5 |
| G4-22 | HT | 0.7 | 0.3 | 2.9 |
| | | | | |
| AVERAGE | | 0.9 | 0.4 | |